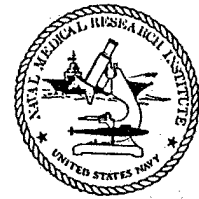


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NMRI 98-09 June 1998



HUMAN DECOMPRESSION TRIAL WITH 1.3 ATA OXYGEN IN HELIUM

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TECHNICAL REVIEW AND APPROVAL

NMRI 98-09

The experiments reported herein were conducted according to the principles set forth in the current edition of the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animals Resources, National Research Council.

This technical report has been reviewed by the NMRI scientific and public affairs staff and is approved for publication. It is releasable to the National Technical Information Service where it will be available to the general public, including foreign nations.

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The Naval Medical Research Institute (NMRI) was tasked to develop helium-oxygen decompression tables for a proposed closed circuit breathing apparatus which will deliver a constant oxygen partial pressure of 1.3 atmospheres (ATA). It was anticipated that the higher PO₂, compared to the currently used 0.7 ATA, would significantly reduce the required decompression times. This report describes the human dive trial that was conducted to explore the effect of the higher PO₂ in reducing decompression time. A sequential dive trial was designed in which the outcome of dives at each step dictated the selection of a profile for the next test. Excessive Decompression Sickness (DCS) outcome resulted in selection of a safer next profile. Conversely, low DCS outcome resulted in selection of a riskier profile (added bottom time or less

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decompression time). A pre-trial probabilistic model, existing 0.7 ATA heliox data and the current 0.7 ATA PO₂ Heliox tables were used to obtain the various profiles for testing. The pre-trial model was calibrated with over 4000 existing heliox (helium and oxygen) and nitrox (nitrogen and oxygen) dives. A sequential dive trial was conducted using pre-set outcome-based trial stopping criteria. A total of 472 dives (160 No-Decompression, 312 Decompression) were conducted at depths from 120 fsw to 300 fsw with 26 cases of DCS and 22 cases with marginal symptoms. The use of a calibrated model provided a selection of profiles with substantially reduced decompression times and satisfactory initial estimates of risk. A pre-set sequential trial provided an unbiased evaluation of individual profiles. It is anticipated that the higher PO₂ can result in a 40 to 50% reduction in decompression times.

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We are grateful to the test subjects for their enthusiastic participation. These dives were technically difficult to execute and unprecedented coordination was required between divers, chamber operators, the gas farm and other participants. The NMRI divers, dive supervisors, dive watch officers and watchstanders made an extraordinary effort to perform these demanding dives. We also thank the NMRI-Diving and Environmental Physiology Dept. Engineering and ET staff for their planning, monitoring and repair support and P.R. Karnik for critical engineering and programming of the data collection process. Dr. R.S. Lillo and Mr. J.M. Caldwell were instrumental in ensuring proper monitoring of diver's breathing gases. Diving Medical Officers participating in this study were: C. Auken, R. Ball, J. Broome, T. Buttolph, D. Gummin, A. Isakov, P. Nyquist, R. Sharpe, C. Toner, D. Valaik.

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As this series spanned several years and succeeded through the efforts of countless participants, an abridged chronology follows to recognize all.

NAVSEA tasking letter 8027 OPR 06X/088 dtd 24 Jun 1991

Tasked NMRI with the development of decompression procedures for the Mark 16 underwater breathing apparatus (helium-oxygen mode at a constant oxygen partial pressure of 1.3 ATA)

08 Sep 95: original protocol submitted.

Principal Investigator:	Homer
Co-Investigators:	Gummin, Isakov, Nyquist
Medical Monitor:	Isakov
Project Officer:	Isakov
Head, Operations Division:	Mailloux
Head, Decompression Program:	Gummin
Command Diving Officer:	Chandler

Head, DEPD:
Scientific Administrator:
CO NMRI:

Homer
Gaughler
Walter

08 Nov 94: memorandum from Homer to the Committee for the Protection of Human Subjects (CPHS); re-submission of protocol 94-04 to provide requested clarification of several points and additional information

18 Nov 94: Memorandum of CPHS protocol revision approval
1.3 Atmosphere Oxygen in Helium Decompression (Phase I); Homer.

28 Nov 94: Memorandum of CPHS protocol approval
Principle Investigator: Homer
Associate Investigators: Gummin, Isakov, Nyquist

24 Apr 95: Memorandum from Homer to CPHS
Notification of Isakov's impending departure:

"LT Isakov, the medical monitor for the subject protocol will shortly be leaving the Command. Effective 1 May 1995, LT Nyquist, a credentialed Undersea Medical Officer and the new Head, Health Monitoring Division, NMRI, will be the medical monitor for the subject protocol".

24 April 95: Memo from Isakov to Homer indicating that on 01 May 95 Nyquist will "assume duties as Head, Health Monitoring Division (Code 34), and also as NMRI Manned Diving Project Officer, to include serving as Project Officer for NMRI Diving Protocol 94-04".

09 May 95: Memo from Homer and Nyquist (Medical Monitor) to CPHS
Requesting modification of the experimental rejection criterion.

09 May 95: Memo from Homer and Nyquist (Medical Monitor) to all DMOs outlining new procedures for rejecting a dive profile.

18 May 95: Memo from Homer and Nyquist to CPHS
"Dr. Homer will be leaving the command on 01 Sep 95. Effective 19 Aug 95 Dr. Flynn will be the new designated Primary Investigator..."

20 Sep 95: Memo from Command Diving Officer (Goehring) to CO NMRI
Request for change of Project Officer.

"LT Nyquist serves as both the Project Officer and the Medical Monitor. To avoid any possibility of a conflict of interest, I respectfully request that LCDR Griffith be assigned the duties of the project Officer, effective immediately. LT Nyquist would remain the Medical Monitor."

26 Sep 95: Memo from Flynn to CPHS with attached signature page to reflect new Department

Head (Harabin) new "Division Head" (Ball) and new P.I. (Flynn).

29 Sep 95: memo from CPHS (Nelson) to PI (Flynn) accepting Griffith's assignment as Project Officer

Fall 95: Dr. Lambertsen (U. Penn) performed an analysis of the 300 fsw profiles with the Penn bubble model.

02 Oct 95: memo from Flynn to CPHS requesting modification to the protocol to modify Sequence 7 (originally 260/20) to permit profile 260/25.

05 Oct 95: memo from CPHS to Flynn accepting personnel changes.

17 Oct 95: memo from CO NMRDC to CO NMRI requesting "appropriate documentation" to reflect change of P.I. (new Investigator Assurance Agreement, Consent Form, Privacy Act Statement).

23 Oct 95: memo from Flynn to Command Diving Officer
re: modification of protocol for the 260 fsw sequence to "reduce the magnitude of the jump between the B and D profiles".

19 Jan 96: memo from Flynn to CPHS, summary of results to date.

01 Feb 96: memo from Head Health Monitoring Division (Nyquist) to DMOs outlines the general plan for the management of DCI for this dive series

01 Feb 96: memo from Head Health Monitoring Division (Nyquist) to Head of Diving Operations (Griffith) addressing pulmonary oxygen toxicity.

05 Feb 96: memo from CPHS to PI (Flynn), approval of protocol modification.

07 Feb 96: memo from CO NMRI to CO NMRDC; approval of greater than minimal risk modification.

14 May 97: Completion Report submitted by Flynn (P.I.) to CPHS.

INTRODUCTION

U.S. Navy Explosive Ordnance Disposal divers use a closed-circuit underwater breathing apparatus (UBA) that electronically controls the oxygen partial pressure to a preset level of 0.7 ATA. Either nitrogen or helium serves as the diluent, depending on the type of diving. A proposed modification to the current UBA would increase the preset oxygen partial pressure level to the higher value of 1.3 ATA based on the premise that decompression time can be substantially reduced, especially following dives to deeper depths. The Naval Medical Research Institute (NMRI) was tasked to develop helium-oxygen decompression tables (17) for use with the proposed UBA for dives up to 300 feet of sea water (fsw) for 25 minutes. A dive trial was conducted at NMRI to explore the effect of this higher PO_2 in reducing decompression time.

Several constraints were imposed for this exploratory effort. Most important among these was the need to minimize the number of dives conducted. Also, because the proposed UBA modification was not yet completed, the specific performance characteristics, including the final PO_2 level and its fluctuations, were unknown. Thus, we had to develop a methodology able to accommodate a final PO_2 level potentially different from the one used in the dive trial. A model was needed with specific attention paid to the role of oxygen levels and kinetics.

In the early 1980s Thalmann (1,15,16) conducted a series of dive trials to develop the current decompression tables (2) for the MK-16 UBA with 0.7 ATA PO_2 in a helium diluent. Table 1 shows a few examples from these tables of decompression times currently required for dives in the depth range of interest. For example, at a depth of 300 fsw and a bottom time of 25 minutes, 6 hours and 50 minutes of decompression are currently required. The additional PO_2 provided by the proposed UBA modification should reduce these decompression times. We

needed to find the shortest possible decompression times consistent with an acceptable risk of decompression sickness (DCS). The dive trial was intended to explore a range of profiles with various decompression times in order to define the boundary between acceptable and unacceptable DCS risk.

A three-tiered trial design (Figure 1) was constructed in which the outcome of dives tested in each tier dictated the selection of profiles for the next tier. Excessive DCS outcome in a tested profile resulted in selection of a safer profile for the next tier. Conversely, low DCS outcome in a tested profile resulted in selection of a riskier profile for the next tier. The selection of appropriate dive profiles to be tested at each tier was the primary problem.

METHODS

Preliminary Model

In earlier work, we developed a probabilistic model for estimating the risk of DCS (3) using a wide range of air and N₂-O₂ (Nitrox) dive data (4). This model was successfully validated in a prospective dive trial (5, 6), and then recalibrated by adding this validation trial data to the original data set. A PC-based dive planner using the final model, USN93, was developed and approved for use by Naval Special Warfare (NSW) personnel (7,8). This experience established a novel methodology wherein an initial model, based on existing data, provided the basis for a dive trial, and the final model then incorporated the results of that trial to fine tune model performance for the eventual application.

Our current task required a similar approach; hence, an appropriate model of DCS risk became necessary. The instantaneous risk of DCS in the USN93 model is calculated as the

weighted sum of relative nitrogen over-pressure in up to three independent tissues. Oxygen does not contribute to DCS risk in this model. While USN93 appears adequate for air or 0.7 ATA PO_2 nitrox dives, it was found to underestimate the risk of DCS for dives where 100% oxygen was breathed during decompression (3,9). Thus, we developed an extension of the USN93 model, with risk contributions from nitrogen, helium and oxygen. Details of this model, referred to as LEM, the calibration data set and the calibration parameters are provided elsewhere (10). This model was calibrated using a data set consisting of 4197 dives, with 216 cases of DCS and 96 cases of marginal symptoms. About half of the dives in the calibration data set derive from air and nitrox profiles including saturation dives and 100% oxygen decompression dives, while the remainder were from heliox ($He-O_2$) or trimix (N_2-He-O_2) dives. Despite the intended application to helium-diluent profiles, nitrox dives were included in the calibration data set because air is breathed both before and after a heliox dive, and some nitrogen exchange takes place during the dive. Thus, calibration of nitrogen gas exchange kinetics is required.

Experimental Design

The three-tier dive trial design is shown in Figure 1. For this trial, a "series" is defined as a given depth with either a specific bottom time (series *D - I*), or a specific decompression time (series *A - C*). A profile is defined as a specific depth/bottom time/decompression time combination within a series. For example, series *A* (see Fig. 5) is at a depth of 120 fsw, with a fixed decompression time (no-stops) and there are seven profiles available for testing within series *A*: Profiles *A* through *G*, each with a different bottom time. [Note *italics* used to denote series and non-italics used to denote profile]. Each series started at the first tier with Profile *A*

(except series *H*). The DCS outcome from testing Profile A determined the selection of profile in the second tier. If Profile A was accepted as safe according to pre-set accept/reject criteria (11,12), the trial proceeded to the second tier to Profile B which was set to be riskier than Profile A. If Profile A was rejected as unsafe, the trial proceeded to the second tier to a safer profile, C. The trial progressed to the third tier in similar fashion. Thus, Profile G was the safest and Profile D was the riskiest of the available profiles in each series.

In the case of a no-decompression (NoD), or more correctly, no-stop, dive series at a given depth, a safer profile had a shorter bottom time than a riskier profile. Similarly, in the case of a dive series with a given depth and bottom time requiring decompression stops, a safer profile had a longer total stop time (TST) than a riskier one. In most cases the safest profile, G, was obtained using the TST from current tables for 0.7 ATA PO₂ in helium (2), but using the model to calculate a stop time distribution for that TST. The riskiest, profile D, was obtained using the calibrated model at a risk level of 5%. Previous dive experience accumulated in the development of the 0.7 ATA PO₂ tables (henceforth referred to as EDU185), was also used wherever applicable (1). Profile A was chosen at a midpoint, in terms of either TST or NoD bottom time, between profiles D and G. For example, in a NoD dive series the bottom time of Profile A was halfway between the bottom times of Profiles D and G, and for a decompression dive series, the TST for Profile A was half way between the TSTs of Profiles D and G. Similarly, Profile B is at a midpoint between Profiles A and D while Profile E is at a midpoint between Profiles A and B. The probabilistic model was used to calculate a stop time distribution for all decompression profiles, based on the given TST.

Preset accept/reject criteria for the sequential design were selected to expedite the

exploration of dive profiles at various risk levels. The intent was to proceed if a dive was found to be "reasonably safe" until a "very risky" region was reached. The maximum number of dives to be done on any one profile was arbitrarily fixed at 32. Three or more cases of DCS on any profile at any time was considered to be too high and the profile was to be rejected as too risky. This rule meant that we would accept 2 cases of DCS in 32 dives as "reasonably safe". The fact that an outcome of 2 cases of DCS in 32 dives may arise from a dive as risky as 18.4% (90% binomial confidence upper limit) lead to the other accept criteria, *i.e.*, the upper 90% confidence limit of any acceptance criteria was to be $\leq 18.4\%$. The selected accept/reject criteria were as follows:

Accept the profile as "reasonably safe" if:

1. 0 cases of DCS are observed in 16 or more dives.
2. 1 case of DCS is observed in 24 or more dives.
3. 2 cases of DCS are observed in 32 or more dives.

Reject the profile as unsafe if:

1. 2 or more cases of DCS are observed in 8 or fewer dives.
2. 3 or more cases of DCS are observed at anytime.
3. 2 or more cases of Type II DCS are observed at any time.
4. 1 "severe" case of DCS is observed at any time.

Monte Carlo simulations of the sequential design (12) stated above (Accept rules 1-3 and reject rules 1-2) resulted in the curve shown in Figure 2. The abscissa represents the true but unknown underlying risk, or probability of DCS ($P(\text{DCS})$), for the profile being tested. The

ordinate represents the probability of accepting the profile as a result of the sequential design criteria. For example, the curve in Figure 2 shows that the chance of accepting a 17.5% or riskier profile is only 10%. This means that we have 90% confidence that we would not accept a 17.5% or riskier profile as safe. Or, to put it another way, we have 90% confidence that we would reject a dive profile that is riskier than 17.5%. Rejection rules 3 and 4, included for safety and morale reasons, will serve to lower the curve in Fig. 2 by a small but unknowable amount.

Subjects

A total of 78 U.S. Navy divers (1 female (subject 64) and 77 males) volunteered after the study was approved by the Committees for Protection of Human Subjects at NMRI and the Naval Medical Research and Development Command. Subjects participated in 1 to 23 dives, with an average of 6 dives per subject. A minimum 60-hour interval was mandatory between subsequent dives for the same subject. The physical attributes of the subjects are given in Appendix 1.

Facilities and Equipment

Chambers R and D of the NMRI Man-Rated Chamber Complex (MRCC) were used for all hyperbaric exposures. The modified UBA capable of delivering 1.3 ATA PO₂ was not available during the dive trial, so PO₂ was maintained by shifting surface supplied heliox mixtures to increasingly higher fractional mixes of O₂ at pre-designated depths during decompression. The D-chamber "wet pot" was equipped with 2 upright underwater bicycle ergometers (Collins Pedalmate 07600, Braintree, MA). Data acquisition system software was installed on a MicroVax 4000 with a VMS 5.3 operating system. The R chamber was equipped

with a digital pressure gauge (DPG2, model 14000, Mensor Corp., San Marcos, TX; depth range 0-450 fsw, accuracy ± 0.05 fsw) with a serial interface.

The breathing gases were mixed at NMRI from 99.997% Helium and 99.6% Oxygen bulk-gas components (Air Products and Chemicals, Inc; Bladensburg, MD). The helium and oxygen content of the resulting mixed gases was certified by gas-chromatographic analysis (Shimadzu GC-9 and GC-14) to an accuracy of 1% relative.

Oxygen partial pressure of the divers' breathing mix was measured using three Teledyne B1 microfuel cell sensors arranged in parallel via A/D converter. These sensors were calibrated at the surface prior to each dive using calibration gases with 13%, 27% and 100% oxygen in helium (0.13, 0.27 and 1.0 ATA PO_2). During dive data acquisition, at least two of the sensors had to be within ± 0.1 ATA of each other for a PO_2 reading to be considered valid. If all of the three sensors were outside the tolerance (*i.e.*, differed from each other by more than 0.1 ATA), the sensors were considered to be malfunctioning and their reading was ignored. The chamber pressure and divers' breathing mixture PO_2 were read at 5-second intervals and logged in an ASCII file. This sampled PO_2 was used during the dive as a rough measure of the oxygen content of the divers' breathing gas and later to establish the details of the timing of gas switches for the final data set. Paramagnetic analysis (Sybron-Taylor) was also used to confirm the oxygen content of the breathing gas during the dive. The recording software allowed the diving officer to mark the exact time at which the subjects entered the wet pot (taken as a single time, that of the 2nd of the 4 divers to enter) so that a depth offset could be added to the chamber pressure, giving diver depth at midchest level. Depths in the final data set are always diver depths, not chamber depths, and reflect the increased pressure due to immersion in the wet pot.

Procedure

Pre-Dive Screening

On the day of each dive, each subject was interviewed by the diving medical officer (DMO) to verify the subject's fitness to dive. Divers were excluded from diving for any of the following conditions: Inability to clear, upper respiratory infection, new or changing joint pain(s), acute infectious disease, new traumatic injury, or any other complaint judged by the DMO to compromise the diver's fitness, or which might cloud a later diagnosis.

Post-Dive Screening

Subjects were required to remain at the MRCC for a minimum of 2 hours after the dive. Subjects were under direct observation by a DMO for the first 10 minutes after surfacing. Each subject was then interviewed and examined by the DMO within 30 minutes and again at 2 to 3 hours and 22 ± 2 hours post-dive. Diving Medical Officer surveillance and reporting followed the same procedure post-treatment.

Dive Procedure

Up to four subjects in wet suits (typically 1/4" neoprene including gloves, boots and hoods with details left to unrecorded personal choice) and MK-20 open-circuit surface-supply full face masks participated in each dive. Water temperature depended on the duration of the dive and ranged from 45°F to 67°F. The recorded water temperatures for each dive are provided in Appendix 2. The subjects were fitted with rectal temperature probes to monitor core body temperature. The dive procedure called for removal of a diver from the water if his core temperature dropped by 2°C from his pre-dive level. This temperature drop was not observed in

any diver in this trial.

Divers entered the chamber at 1 ATA breathing air and donned face masks that initially delivered a 79% N₂, 21% O₂ mix. The divers then entered the wet pot and when all the face masks were confirmed to be fitted properly with no leaks, the breathing gas mix was switched to 100% oxygen and the chamber was pressed to 8 fsw with air (diver depth of 12 fsw with depth offset (4 fsw) of the wet pot to diver midchest level). The breathing mix was then switched to the predesignated heliox mix that would provide 1.3 ATA O₂ at bottom depth and the chamber was immediately pressed on air at 60 fsw/min to the bottom depth. The chamber was ventilated with air as needed during the dive to maintain a breathable atmosphere. The breathing time for 100% oxygen was kept to a minimum, typically 1 to 1.5 minutes. Bottom time was measured from leaving 12 fsw to leaving bottom.

Unrestrained subjects exercised on bicycle ergometers set at a workload of 50 or 75 watts, in cycles of 5 minutes on and 5 minutes off, beginning upon arrival at bottom. During the 300 fsw dives the work cycle was decreased to 4 min on and 4 min off. The ergometer workload was intended to simulate a moderate working dive and required subjects to pedal at 60 rpm with guidance from tachometer lights. In pre-trial calibration of the ergometers at 1 ATA, dry and breathing air, subjects consumed 1.5 to 3.0 liters/min of oxygen at these workloads. Subjects stopped exercising and rested during the decompression.

At the end of bottom time, the subjects were decompressed at 30 fsw/min and their breathing gas mix was switched at predesignated depths to increasingly higher fractional mixes of oxygen in helium such that their PO₂ remained within the 0.9-1.3 ATA range during travel and decompression. The chamber decompression rate slows near the surface, so that the final 20 fsw

of travel typically required about 1 minute. Upon surfacing of the chamber, the divers climbed out of the wet pot and simultaneously removed face masks, thus returning to breathing 1 ATA air. The recording software allowed the diving officer to mark the exact time at which the subjects exited the wet pot, taken as a single time, that of the 2nd of the 4 divers to exit.

Depth, time and PO_2 breathed by the divers during the dive were recorded every 5 seconds by the real-time software system. Depths reported are diver's depth at midchest level. Figure 3 shows a plot of a typical NoD dive. The numbers along the PO_2 curve correspond to the divers' breathing gas mix changes. Figure 4 shows a dive profile requiring decompression stops and 14 different gas mixes. Both of these figures are illustrations of the extraordinarily complicated gas switching demands for this dive trial. The time lag from when a gas switch was made to the time the new mix was detected by the PO_2 sensors was typically less than 15 seconds. The divers should have experienced the same lag time in gas delivery as the sensors. The recorded files were then converted to the standard NMRI dive data format (4), and file NMR9404.DAT was created for archives and eventual analysis. This data set contains all necessary details of the dive exposure, including time, depth, exact gas mix delivered, the timing of each gas switch and the DCS outcome. Appendix 6 contains a single line summary for each profile contained in the data set.

RESULTS

The first three dive series, *A*, *B* and *C*, consisted of NoD dives at 120, 160 and 200 fsw, respectively, with a TST of zero. Dive series *D* through *I* included dives from 160-300 fsw with varying TSTs. Note that specific positions in the three-tier design are referred to as profiles A

through G (Figure 1), and each dive series, consisting of several tested profiles, is denoted by letters A through I. For clarity, *italic* letters are used to represent the dive series and appear first in the dive name. The second letter in the dive name (not italic) represents the specific profile within that series. Figures 5 through 13 show the details of each dive series as it was initially planned and how it was actually executed. The bold type represents the path taken between tiers, while the dotted arrows show the planned but unexecuted dives. The observed results (DCS/Dives) are provided for each tested profile, and DCS cases are shown in parentheses for cross reference with Appendices 4, 5 and 6. DCS cases are referred to by a single lower case letter, and marginal cases, defined as fleeting symptoms that were not treated are referred to by double lower case letters.

Core temperature was monitored during the dives to assure that divers did not become hypothermic. No diver experienced a core temperature drop in excess of the 2.0°C safety limit. Some core temperature readings were recorded, and for the 150 dives (32% of total) with complete recordings, the mean drop in core temperature, from pre-dive to final surfacing, was $0.5 \pm 0.6^{\circ}\text{C}$, with a range of -0.7 to 1.9°C. Water temperatures for dive profiles with complete core temperature recordings ranged from 55 to 67°F and in-water time for these profiles ranged from 35 to 215 minutes.

In most dive series the TST of the safest profile G (bottom right) in the three tier design was obtained from existing 0.7 ATA PO₂ tables and the riskiest profile D (bottom left) was obtained by using the model at approximately a 5% risk level. Data from the previous dive trial, EDU185, was also used wherever applicable. For example, in dive series A, the riskiest profile was obtained using EDU185 experience (see Fig 5), while in dive series *D* and *E* the safest

profiles were obtained using EDU185 experience (Fig 8 and 9). The sources of the safest and the riskiest profiles for each series are shown at the bottom of Figures 5 - 13. Figures 8 - 13 show those series requiring decompression stops and provide the stop time distributions for all profiles planned, along with pertinent information from the 0.7 ATA PO₂ in Helium Tables. Even when the TSTs were obtained from the 0.7 ATA Table or from EDU185 experience, the stop time distribution was optimized using the model. Thus, the model provided a uniformity to the planned profiles despite their diverse origins.

Midway through the trial, modifications to the original design were made to ensure diver safety and minimize the trial size. As explained previously, almost all dive series started at the first tier with profile A and proceeded in the direction dictated by the outcome of that tier. In fact, for dive series A through G, profile A was found to be safe enough to proceed to the riskier profile B. From this accumulated experience, the first tier was skipped for dive series H (see Fig 12). The D profiles, the riskiest profile in each series tested in series A - G, resulted in 12 cases of DCS and 2 marginal cases out of 64 dives (19.1% incidence). Since this was higher than the expected 5%, the D profiles for series H and I were computed at 4% instead of at 5% as originally planned. Profile choices for series I were also revised from the original plan. In series A through G, the A profiles resulted in only 2 cases of DCS and 4 marginals in 131 dives (1.8% incidence). Based on this experience, profile A from the original plan for series I was moved to the position of profile G, and all intermediate profiles were recomputed. The final plan before series I started is shown in Figure 13.

Table 2 shows the summary of dives and the observed outcomes. The number of DCS cases of Type II are shown in parentheses and case references from appendices 4 and 5 are in

square brackets. Again, the first letter (*italics*) in the dive name designates the dive series and the second letter represents the specific profile. Appendix 2 is the chronological record of all dives successfully completed. Appendix 3 is a matrix of dive exposure by subject. In preparation for this report, a panel of NMRI DMOs familiar with the trial reviewed all medical events recorded during the trial. Using the standardized criteria as presented in Appendix 7, this review resulted in the addition of two DCS and nine marginal cases to the results. These post-trial diagnosed cases and marginals are indicated by an asterisk (*) in their respective appendices. Appendix 4 provides the details for all DCS cases and Appendix 5 details all marginal events.

Two separate dive trials related to this study were conducted following completion of the trial described in this report. In one, dives were conducted exactly as described in this report for Profile IE, with the exception that nitrogen was used as the inert gas in the breathing mix during decompression, beginning with arrival at the first decompression stop. Sixteen dives were completed on this profile, with three DCS cases and two marginal cases observed. Details of the conduct of this nitrogen-switching trial are given by Flynn (13). In the second trial, a 300 fsw, 25 min-bottom-time dive was conducted as described in this report, with the exception that a fixed 32% O₂ in He mix was breathed beginning with arrival at the first decompression stop and 100% O₂ was breathed beginning with arrival at the 30 fsw decompression stop. Thirty-two dives were conducted on this profile, with one DCS case observed. Details of the conduct of this emergency-bailout trial are given by Flynn (14).

DISCUSSION

The objective of this study was to explore a range of profiles to demonstrate the benefit of

the proposed higher O₂ level compared to existing 0.7 ATA PO₂ tables (2). The study required a range of profiles that included some "safe enough" to build confidence in the design and some "risky enough" to define the unacceptable risk region.

It should be noted that in no case was an initial profile of a series rejected as unsafe. This indicated that our initial choice for profile A was "safe enough". Tables 3 and 4 compare these starting A profiles to those from 0.7 ATA PO₂ tables. Table 3 shows that 50% or more NoD bottom time was gained in profile A, but that this gain came at a cost of DCS cases even though it was acceptable by the sequential design. A total of 64 NoD dives on profile A (series A, B and C) resulted in 2 cases of DCS (none of Type II) and 4 marginal cases. Table 4 shows that a reduction in TSTs of A profiles compared to corresponding 0.7 ATA PO₂ schedules was substantial (average 45%), and quite safe since no cases of DCS and 3 marginals were observed in 83 dives. Thus, our choice of starting profiles in each dive series was reasonably safe and also provided considerable benefit over the 0.7 ATA PO₂ tables. It is also apparent that the additional PO₂ delivered by the proposed UBA will be most beneficial in reducing decompression times but may not significantly increase NoD bottom times in the depth range we tested.

Stop time distributions of the tested A profiles were different from those required by the 0.7 ATA PO₂ tables. (See Figures 8 - 13 for the stop time distributions.) There is no ten foot stop for the tested profiles since it will be mechanically difficult for the rig to maintain 1.3 ATA PO₂ (almost 100% O₂) at ten feet. The 0.7 ATA PO₂ tables require a much deeper first stop than that required by the tested A profiles. Table 5 compares the first stop depth of the A profiles to that required by the 0.7 ATA PO₂ table. The new profiles allowed a longer initial "pull" and shorter TSTs while proving safe.

We also succeeded in exploring a range of profiles wide enough to test the risky boundary such that we know what kind of dive profiles are to be avoided. The 91 dives conducted on the riskiest profiles (D), including the NoD dive series, resulted in 13 cases of DCS (6 type II) and 2 marginals for a 14.5% observed incidence. The 87 tested D profiles which required decompression stops (not NoD), required, on average, 78% less TST than the corresponding 0.7 ATA PO₂ table (see Table 6) and resulted in a high DCS rate (14.0%). This experience, with special attention given to the time course of DCS events, will be useful in handling emergency situations and in devising surface decompression procedures.

Figure 14 shows the observed and predicted DCS incidence for the trial data categorized by profiles: A, E, B and D. (Note that E profiles are safer than B profiles.) The pair of dash-dotted lines give 95% binomial confidence limits around the observed incidence (Marginal cases of DCS are ignored for this graph). The model's predicted dose response is fairly flat while the observed incidence rate rises sharply at D profile. The predictions are within the 95% confidence limits for A, E and B profiles but clearly fall short for the D profile. This level of mismatch is not unexpected since we are extrapolating outside of the calibration data set. In fact, had the observed incidence followed the predicted dose response, that would indicate failure to test the unacceptable risk boundary. In general, the pre-trial model predictions were quite adequate for the purposes of this exploratory trial.

The dive trial proceeded from start to finish with very little "tinkering". A committee of DMOs discussed the severity of DCS in each case and decided whether a stopping criteria was met (rejection rule 4) and diver safety was always paramount in these discussions. As explained earlier, we only modified our pre-set planned dives on dive series *H* and *I*. However, the planned

profiles were never altered once a dive series started. There is often a tremendous temptation to change the planned dive during a trial because of personal biases. Artifactual associations are difficult to avoid in an experimental environment such as this. In the day-to-day evolution of a trial, there are as many opinions about how risky a specific profile is going to be as there are individuals involved, and each proceeds to search for outcomes to support that bias. Given that the number of divers and evaluators (DMOs) was limited, it was impossible to design a blind trial. The divers, when not participating as subjects, were involved in running the chambers, and several dive-qualified DMOs also participated as subjects. Hence, following pre-set stopping criteria was essential to avoid personal biases in evaluating individual profiles.

CONCLUSIONS

The present task did not require the production of a set of decompression tables. It requested an estimate of the decompression advantage of the proposed higher oxygen mixture, and that advantage has been clearly shown to exist. An advantage of several minutes (important as a percentage of bottom time) in No-decompression time was shown. More importantly, longer dives were able to be completed with 40-50% reductions in total decompression time.

The use of a probabilistic, multi-gas decompression model, calibrated with a wide range of dive data, provided a selection of profiles with substantially reduced decompression times and satisfactory initial estimates of risk. Following pre-set stopping criteria enabled the unbiased evaluation of individual profiles. We also succeeded in minimizing the number of dives conducted, yet acquired a data set with a wide range of profiles and observed DCS incidence. A comparable earlier dive trial (1), from which the 0.7 ATA PO₂ tables were developed, involved

174 subjects, 1582 dives and 57 cases of DCS. In comparison, this 1.3 ATA PO₂ trial involved 78 subjects, 472 dives and 26 cases of DCS. The greater DCS incidence rate observed in this trial (6.0%) relative to the previous one (3.6%) is due to the current trial design which aimed to detect the unacceptable risk region in as few dives as possible. Through the methods described in this report, this dive trial was designed to objectively use the experience gained from a number of previous dive trials to maximize the value of each dive undertaken. This type of design provides the most information with fewest number of dives for decompression table development.

The major lasting product of this work is the data set for (re)calibration of a probabilistic model. The data quality satisfies the criteria for Primary Data established in earlier nitrox work (4)). The risk levels and decompression times of these dives clearly span the region of interest. Evidence of the pre-trial model having an overly shallow dose-response shape (Fig. 14) indicates a better model would be useful, especially for more severe dives, but even this pre-trial model showed an impressive ability to place dives within the desired risk range.

Remaining steps to produce a final set of tables can be anticipated. Primarily, recalibration of the model including the data from this trial. Then, review of model estimates of safety should include examination of whether qualitatively more severe DCS cases tended to cluster above some dive severity "threshold", or are distributed throughout depth-time-TST space. Actual testing of delivered hardware is needed to see how closely the final UBA maintains 1.3 ATA oxygen. Rig performance will then need to be incorporated into programs generating candidate acceptable profiles. Preparation of candidate no-decompression limits and decompression schedules at several risk levels will allow productive discussions with officers making the risk management decisions.

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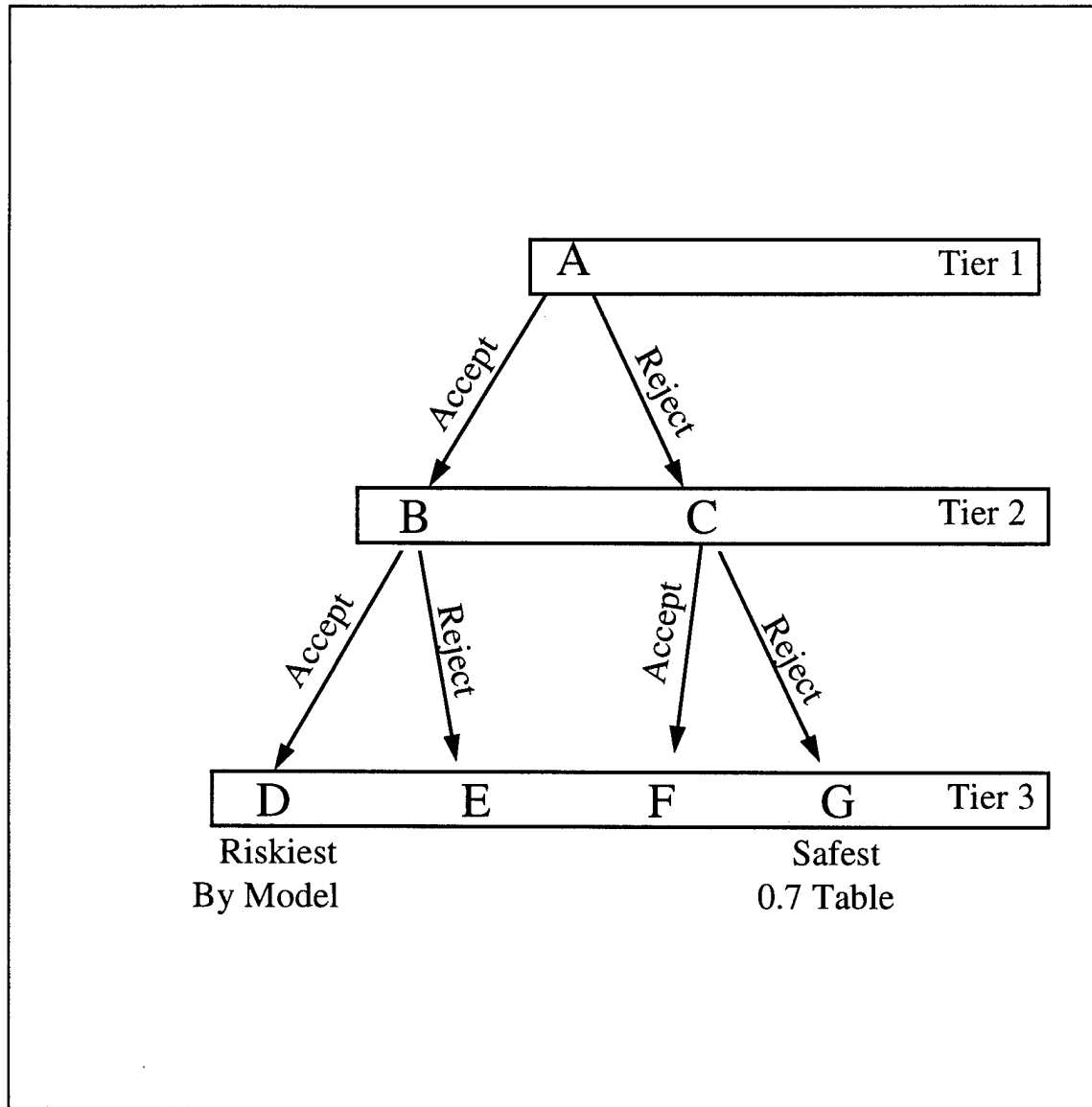


Figure 1: A prototype dive series with the three-tier design. Testing begins with Profile A (Tier 1) and proceeds according to the Accept/Reject criteria as stated in *Experimental Design*.

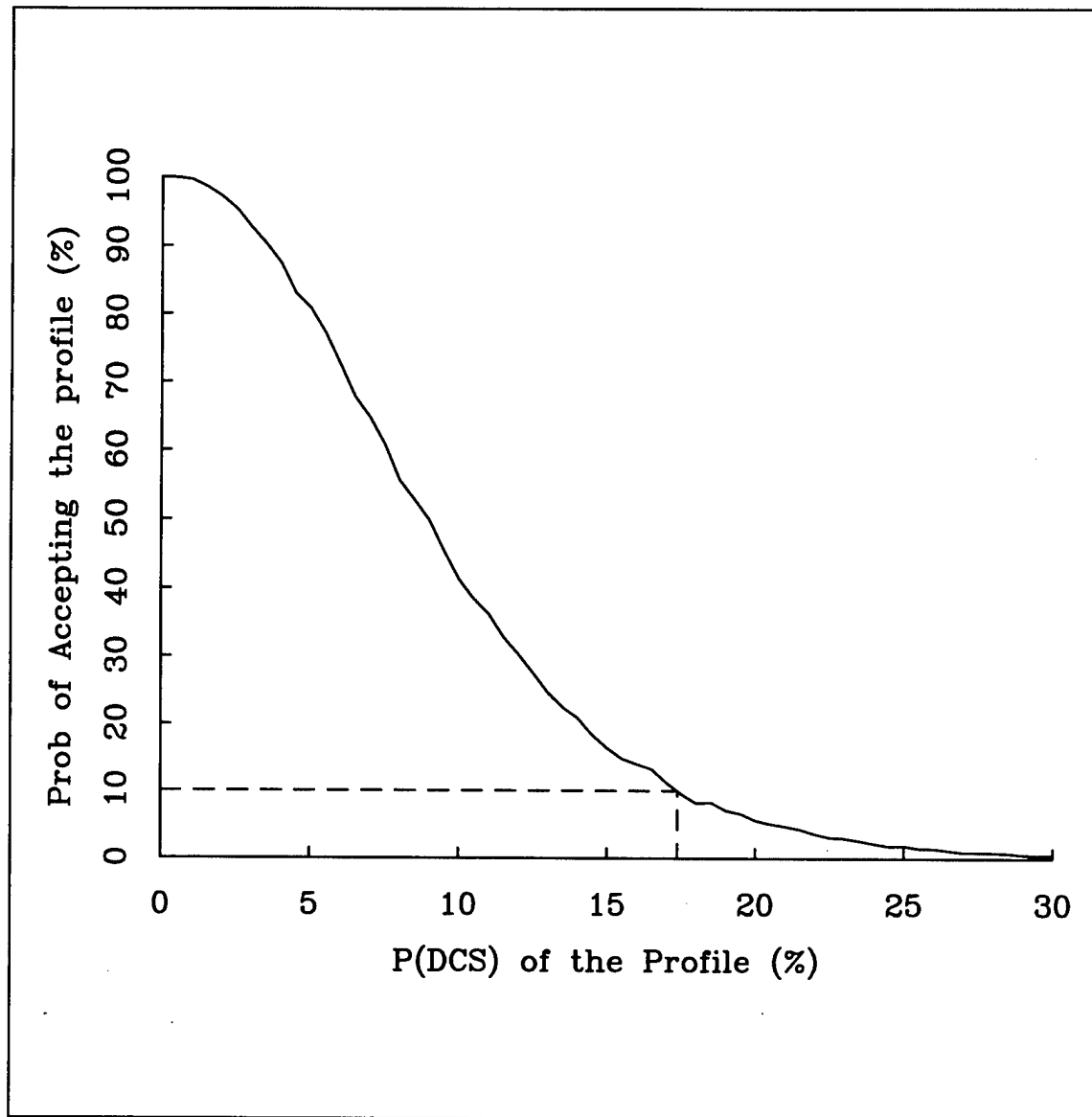


Figure 2: Monte Carlo simulation of the sequential design. The abscissa represents the true but unknown underlying risk, or probability of DCS ($P(\text{DCS})$), for the profile being tested. The ordinate represents the probability of accepting the profile as a result of the sequential design criteria. The slight bumps in the curve would presumably disappear if an even larger number of Monte Carlo simulations were used for each plotted point.

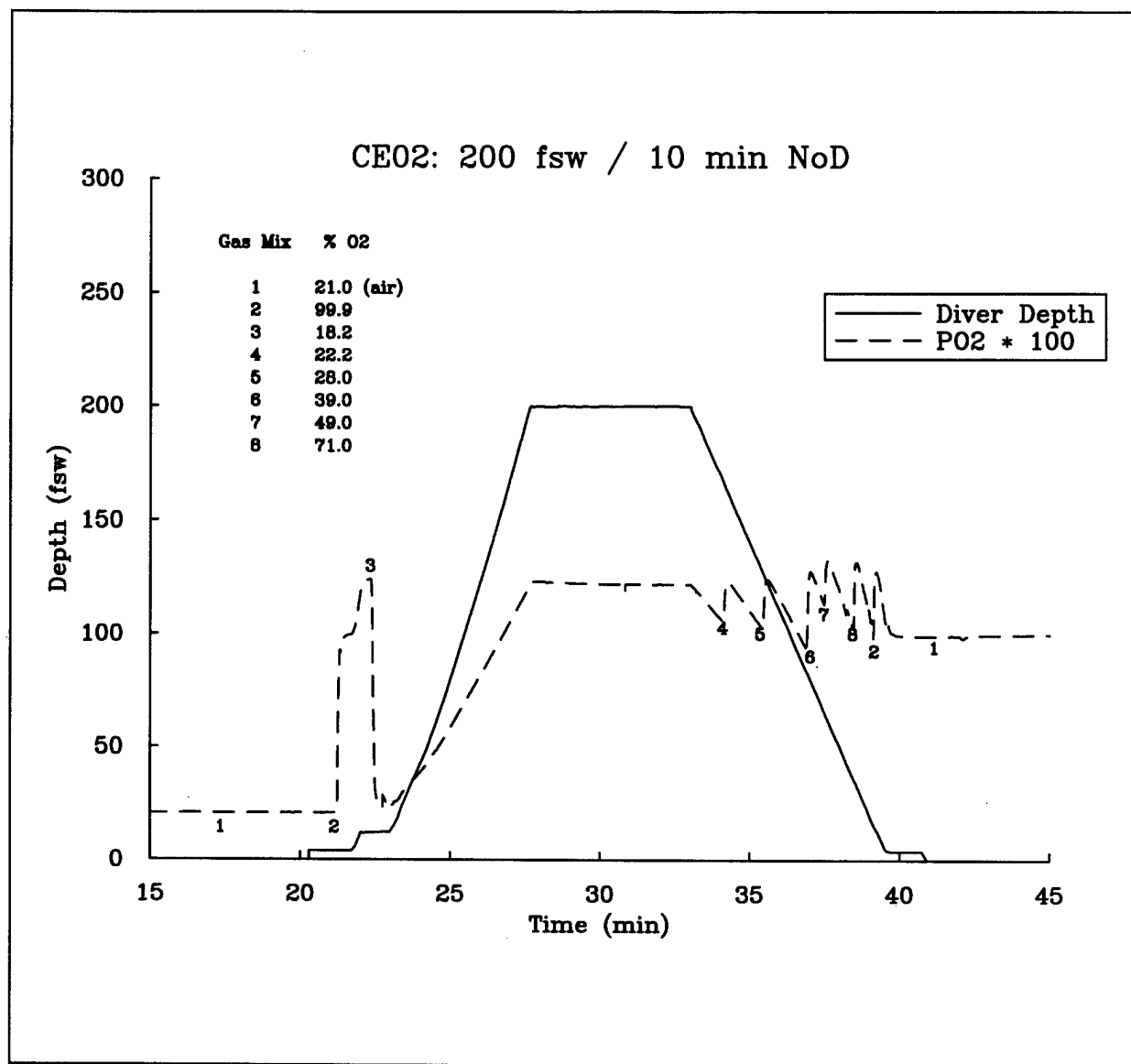


Figure 3: A plot of E profile in the NoD dive series C. Solid line represents diver depth at mid-chest level. Dashed line represents PO_2 (value can be read from y-axis as ATA X 100; for example, the pre-dive value of 21.0 on the y-axis represents a PO_2 of 0.21 ATA). Numbers along the PO_2 curve indicate timing of gas switches. Note that PO_2 remains in the 0.9 to 1.3 ATA range during decompression.

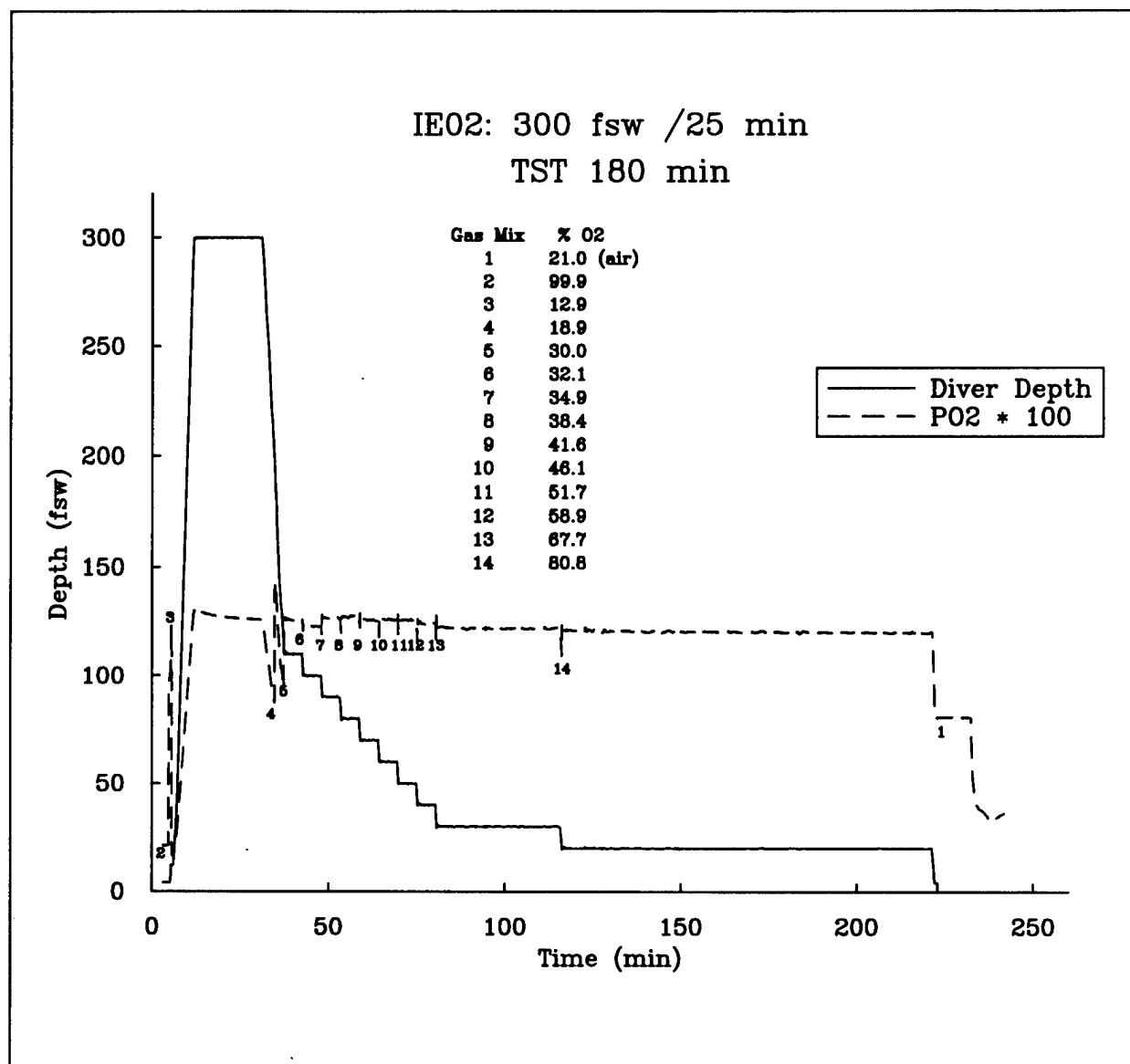
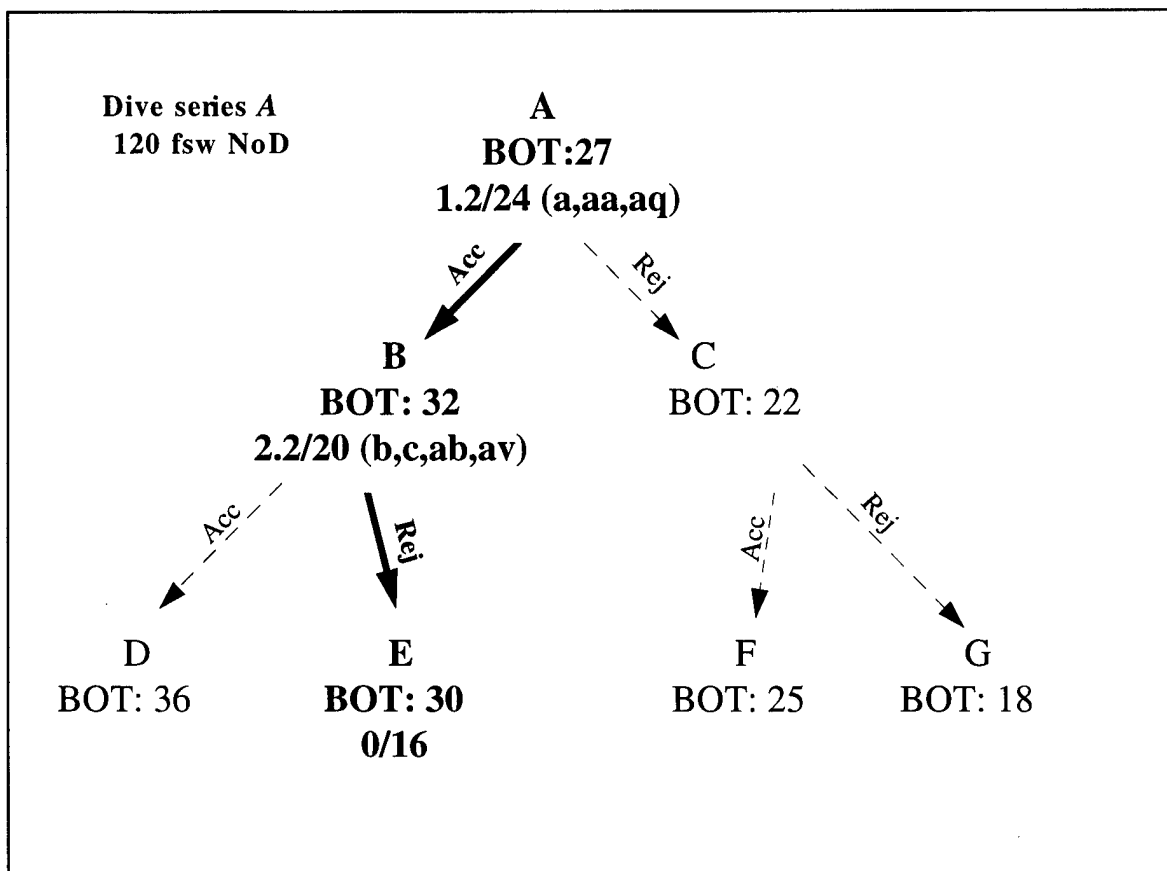


Figure 4: A plot of E profile from the dive series *I*. Solid line represents diver depth at mid-chest level. Dashed line represents PO_2 (value can be read from y-axis as ATA X 100; for example, the pre-dive value of 21.0 on the y-axis represents a PO_2 of 0.21 ATA). Numbers along the PO_2 curve indicate timing of gas switches. Note that PO_2 remains in the close to 1.3 ATA during decompressions stops and travel.

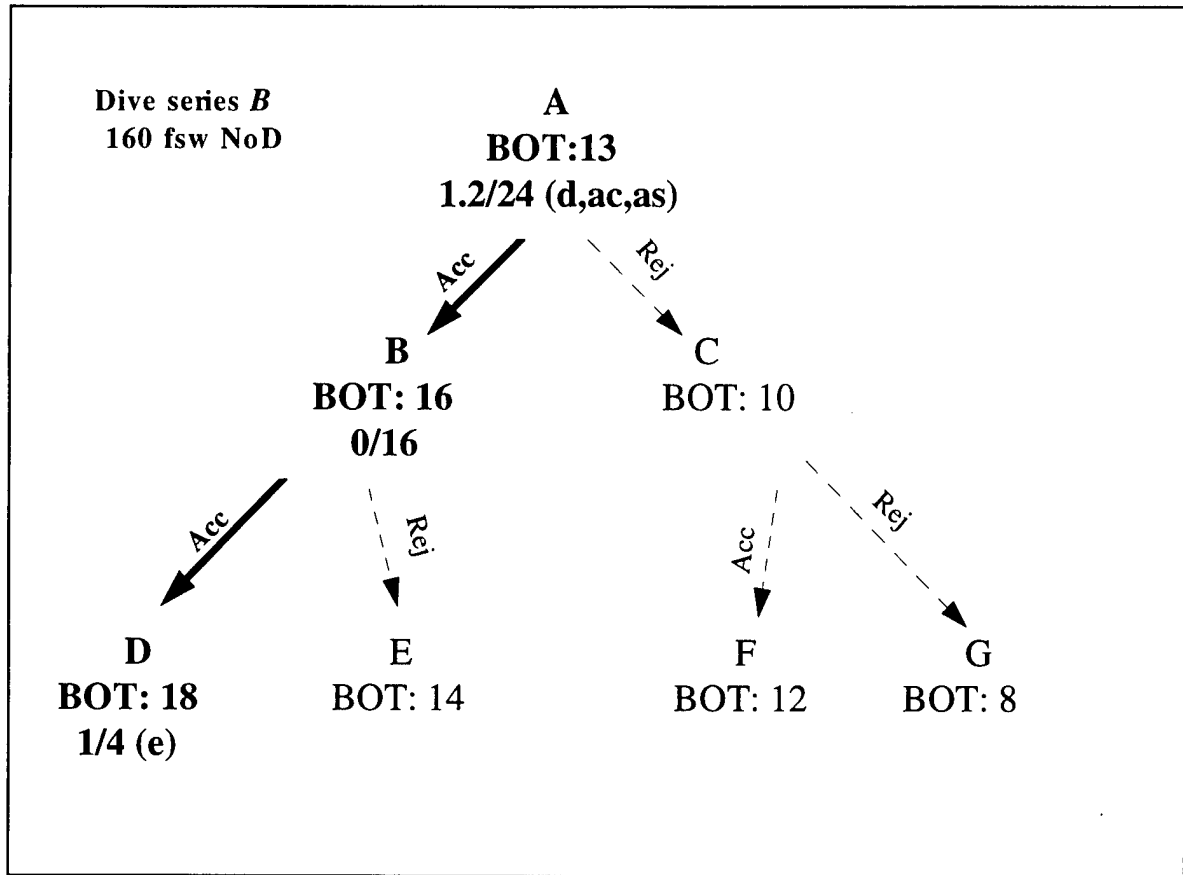


Riskiest Profile D: from EDU185 experience

Safest Profile G: from 0.7 Table NoD Limit 18 min

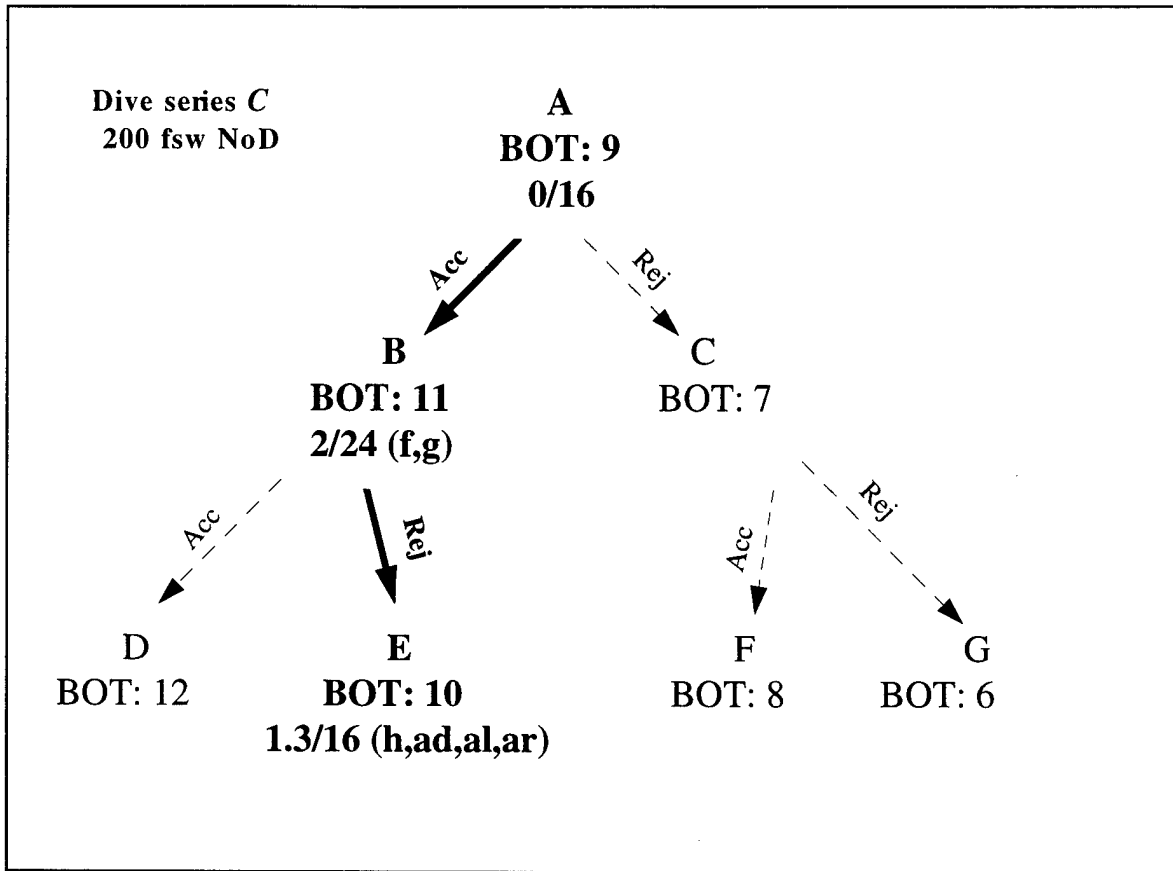
Figure 5: Dive series A - NoD dive at 120 fsw for variable Bottom-time (BOT).

The bold type represents the path taken between tiers, while the dotted arrows show the planned but unexecuted dives. The observed results (DCS/Dives) are provided for each tested profile, and DCS cases are shown in parentheses for cross reference with Appendices 4, 5 and 6. DCS cases are referred to by a single lower case letter, and marginal cases are referred to by double lower case letters.



Riskiest Profile D: by the model
 Safest Profile G: from 0.7 Table NoD Limit 8 min

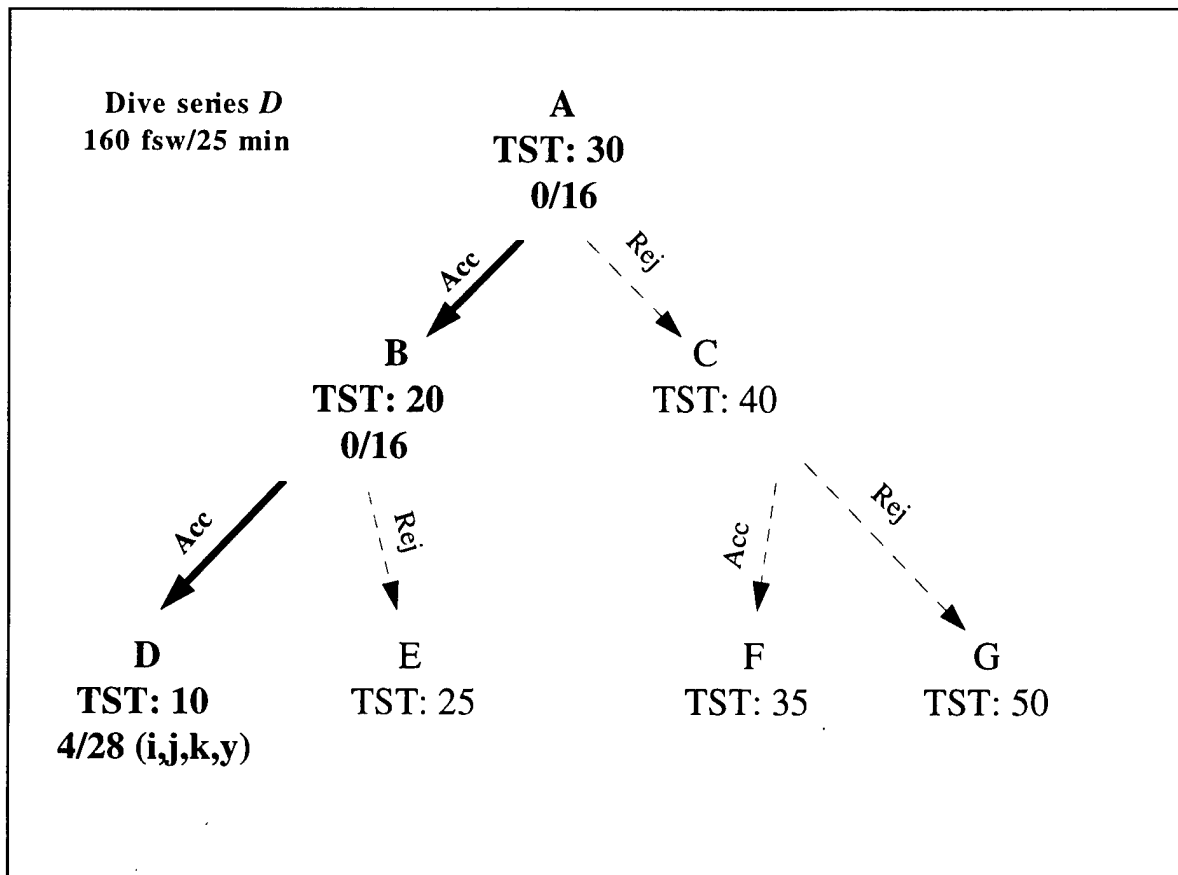
Figure 6: Dive series B - NoD dive at 160 fsw for variable Bottom-time (BOT)



Riskiest Profile D: by the model

Safest Profile G: from 0.7 Table NoD Limit 6 min

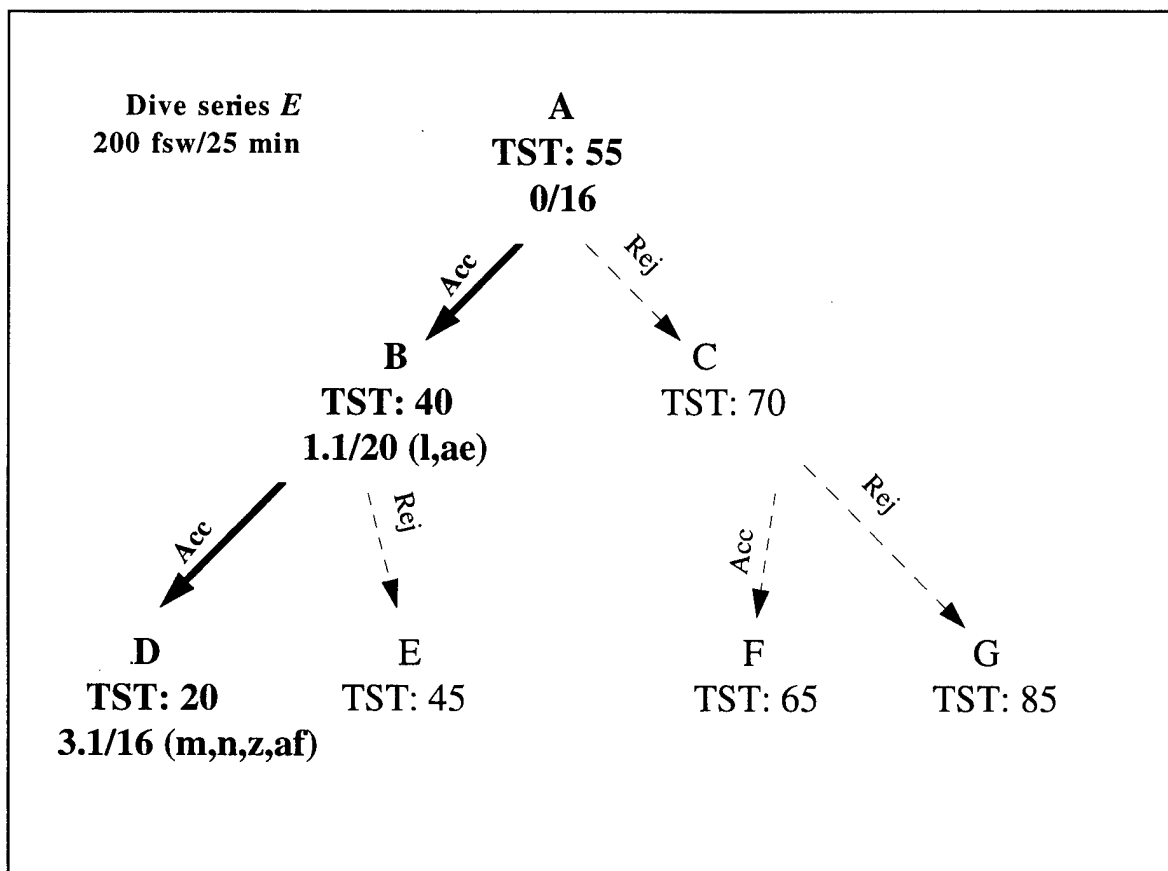
Figure 7: Dive series C - NoD dive at 200 fsw for variable Bottom-time (BOT)



	--Stop Depth--				TST
	40	30	20	10	
Profile A:	5	5	20		30
Profile B:	5	5	10		20
Profile C:	5	5	30		40
Profile D:		5	5		10
Profile E:	5	5	15		25
Profile F:	5	5	25		35
Profile G:	5	5	40		50
0.7 Table:	9	9	17	22	57

Riskiest Profile D: by the model
 Safest Profile G: from EDU185 experience

Figure 8: Dive series D - 160 fsw for 25 min requiring decompression of TST min.

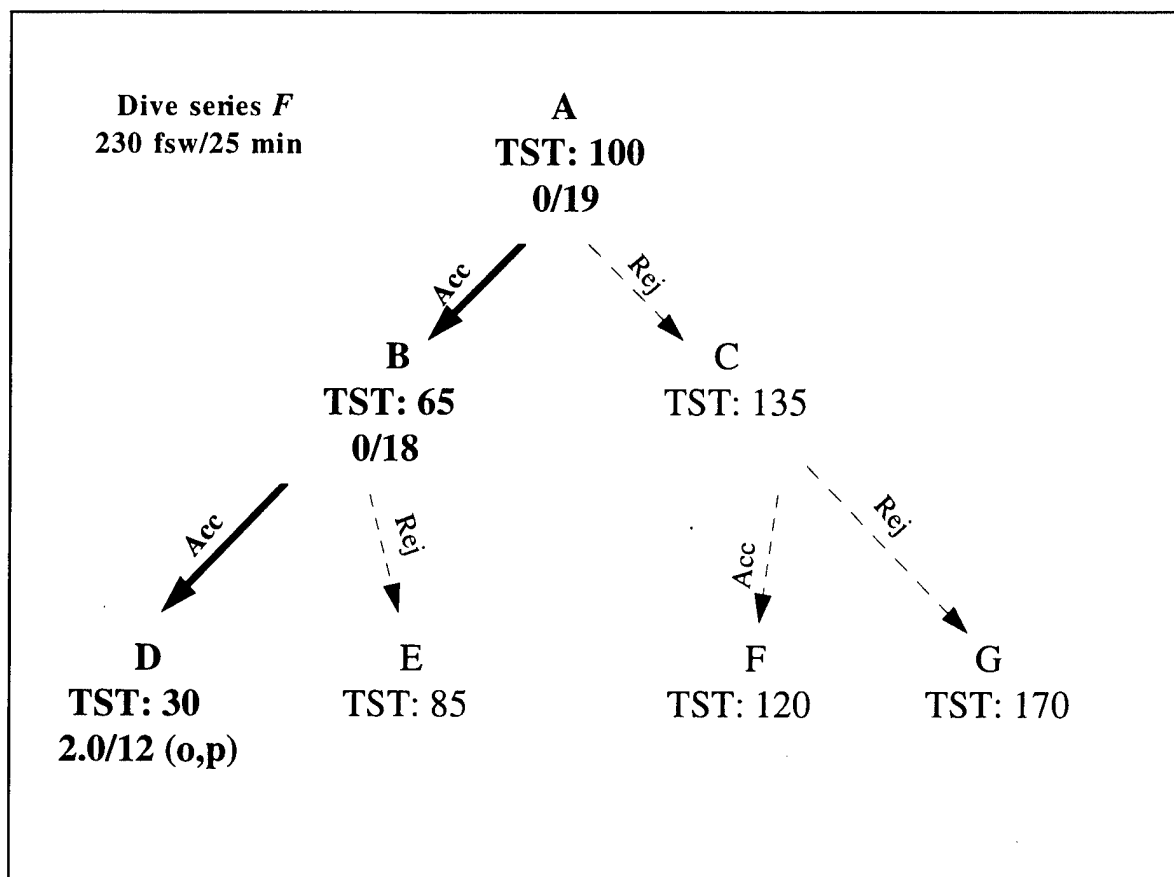


	----- Stop Depth -----								TST
	80	70	60	50	40	30	20	10	
Profile A:			5	5	5	5	35		55
Profile B:			5	5	5	5	20		40
Profile C:			5	5	5	5	50		70
Profile D:				5	5	5	5		20
Profile E:			5	5	5	5	25		45
Profile F:			5	5	5	5	45		65
Profile G:			5	5	5	5	65		85
0.7 Table:	2	6	9	9	10	21	22	22	101

Riskiest Profile D: by the model

Safest Profile G: from EDU185 experience

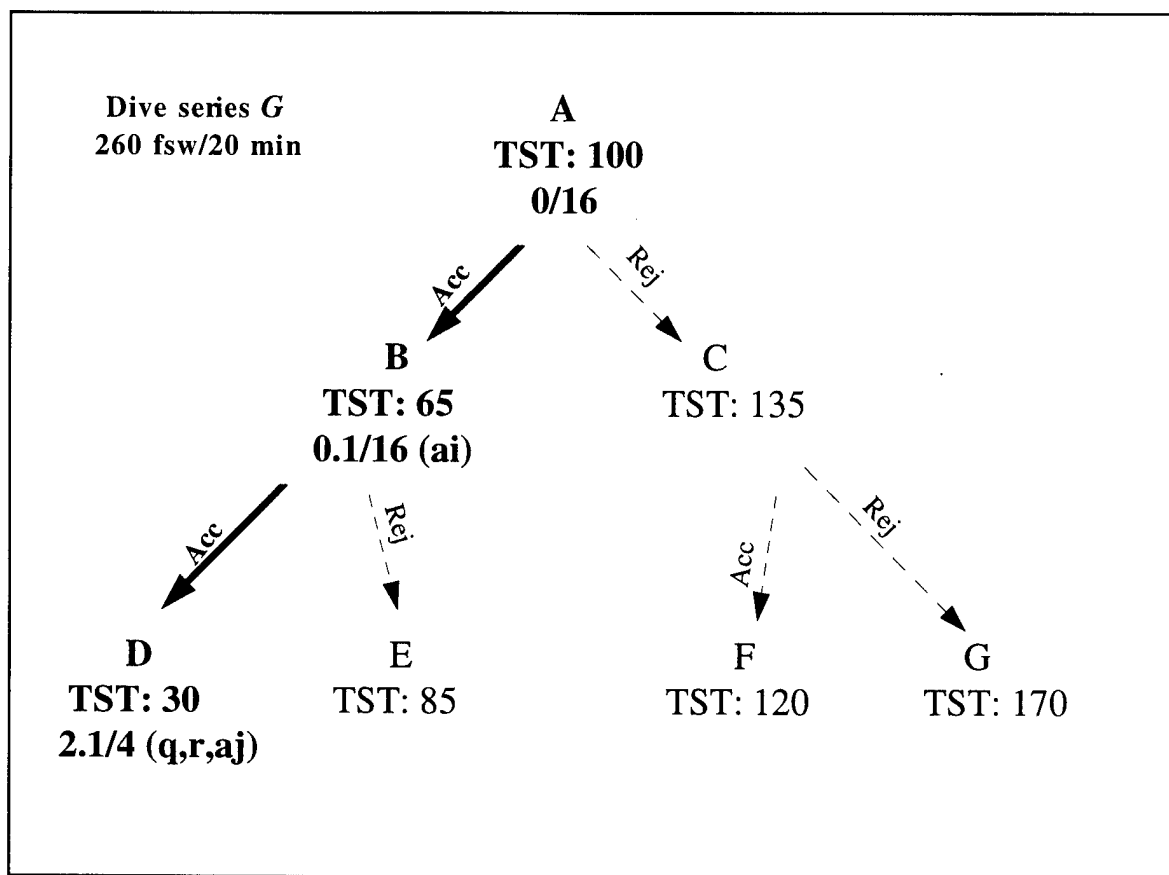
Figure 9: Dive series E - 200 fsw for 25 min requiring decompression of TST min.



	----- Stop Depth -----										TST
	100	90	80	70	60	50	40	30	20	10	
Profile A:			5	5	5	5	5	5	70		100
Profile B:			5	5	5	5	5	5	35		65
Profile C:			5	5	5	5	5	5	105		135
Profile D:				5	5	5	5	5	5		30
Profile E:			5	5	5	5	5	5	55		85
Profile F:			5	5	5	5	5	5	90		120
Profile G:			5	5	5	5	5	5	140		170
0.7 Table:	4	5	9	10	9	9	22	22	22	57	169

Riskiest Profile D: by the model
Safest Profile G: from 0.7 Table

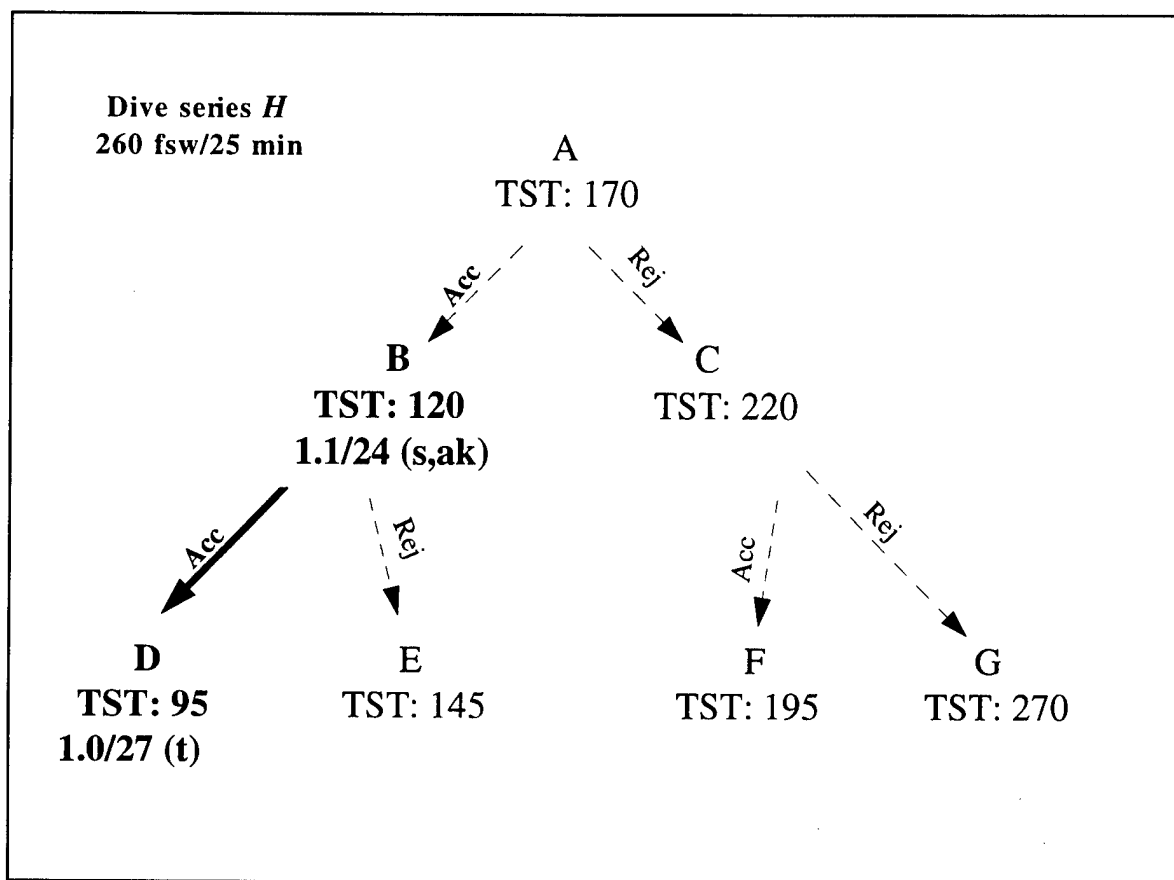
Figure 10: Dive series F - 230 fsw for 25 min requiring decompression of TST min.



	-----Stop Depth-----												TST
	120	110	100	90	80	70	60	50	40	30	20	10	
Profile A:					5	5	5	5	5	5	70		100
Profile B:					5	5	5	5	5	5	35		65
Profile C:					5	5	5	5	5	5	105		135
Profile D:						5	5	5	5	5	5		30
Profile E:					5	5	5	5	5	5	55		85
Profile F:					5	5	5	5	5	5	90		120
Profile G:				5	5	5	5	5	5	5	135		170
0.7 Table:	3	3	4	4	7	10	9	9	13	22	22	58	164

Riskiest Profile D: by the model
 Safest Profile G: from 0.7 Table

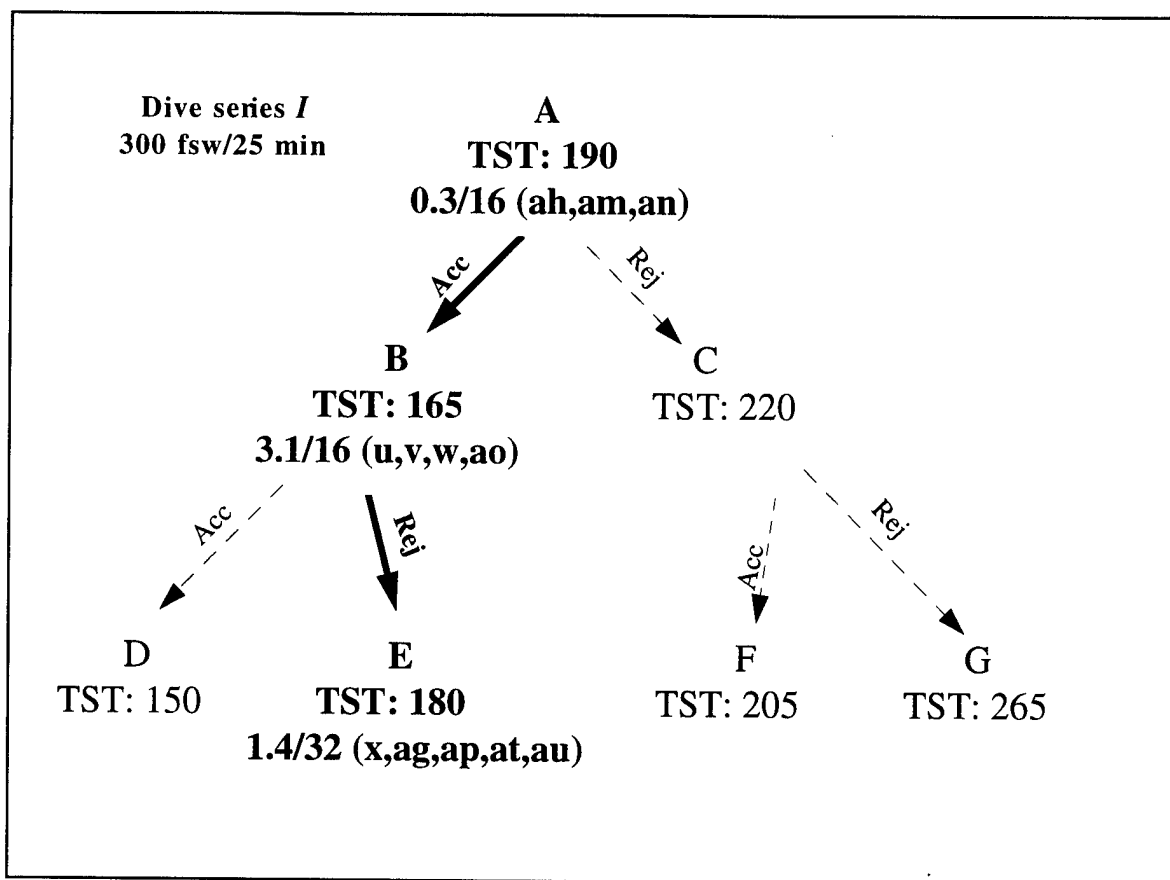
Figure 11: Dive series G - 260 fsw for 20 min requiring decompression of TST min.



	-----Stop Depth-----													TST
	130	120	110	100	90	80	70	60	50	40	30	20	10	
Profile A:				5	5	5	5	5	5	5	10	125		170
Profile B:					5	5	5	5	5	5	5	85		120
Profile C:				5	5	5	5	5	5	5	30	155		220
Profile D:					5	5	5	5	5	5	5	60		95
Profile E:					5	5	5	5	5	5	5	110		145
Profile F:				5	5	5	5	5	5	5	20	140		195
Profile G:			5	5	5	5	5	5	5	5	45	185		270
0.7 Table:	2	4	4	9	10	9	9	9	22	22	22	32	113	267

Riskiest Profile D: by the model
Safest Profile G: from 0.7 Table

Figure 12: Dive series *H* - 260 fsw for 25 min requiring decompression of TST min.



	-----Stop Depth-----																TST
	160	150	140	130	120	110	100	90	80	70	60	50	40	30	20	10	
Profile A:					5	5	5	5	5	5	5	5	5	5	30	115	190
Profile B:						5	5	5	5	5	5	5	5	5	25	100	165
Profile C:					5	5	5	5	5	5	5	5	5	5	45	130	220
Profile D:						5	5	5	5	5	5	5	5	5	20	90	150
Profile E:						5	5	5	5	5	5	5	5	5	35	105	180
Profile F:					5	5	5	5	5	5	5	5	5	5	40	120	205
Profile G:			5	5	5	5	5	5	5	5	5	5	5	5	70	145	265
0.7 Table:	4	4	3	6	10	9	9	9	10	15	22	21	22	44	109	113	410

Riskiest Profile D: by the model
 Safest Profile G: from current dive trial experience

Figure 13: Dive series I - 300 fsw for 25 min requiring decompression of TST min.

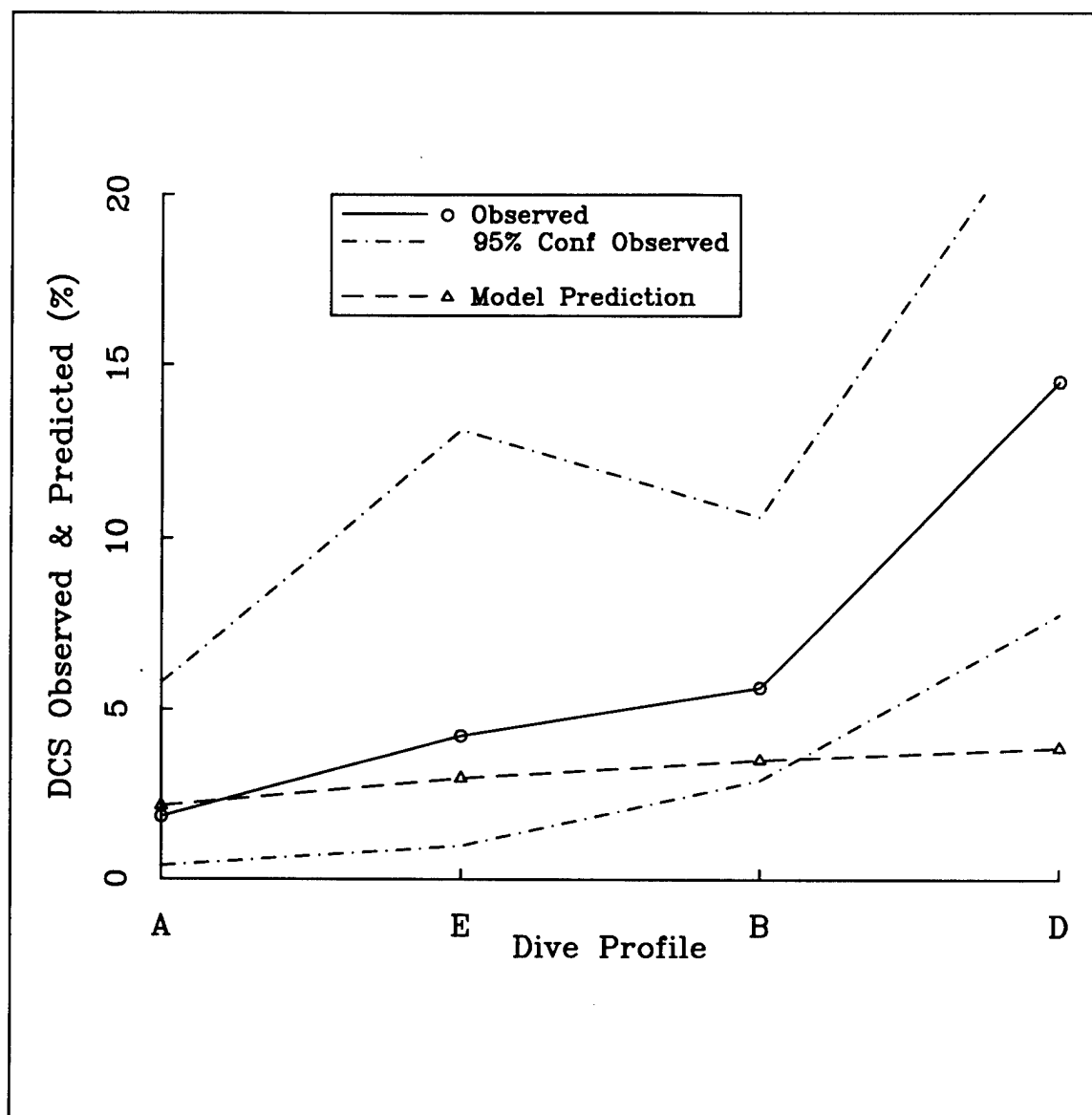


Figure 14: Observed vs predicted DCS in the dive trial.

Table 1: Sample decompression times
for 0.7 ATA PO₂ in Helium (2)
TST = Total Stop Time

Depth (fsw)	Bottom Time (min)	TST (min)
160	25	57
200	25	101
230	25	169
260	25	267
300	25	410

Table 2: Summary of Dives						
Dive Name	Depth (fsw)	Bot (min)	TST (min)	Dives	DCS (Type II) [cases]	Marg [cases]
AA	120	27	0	24	1[a]	2[aa,aq]
AB	120	32	0	20	2 (2)[b,c]	2[ab,av]
AE	120	30	0	16	0	0
BA	160	13	0	24	1[d]	2[ac,as]
BB	160	16	0	16	0	0
BD	160	18	0	4	1 (1)[e]	0
CA	200	9	0	16	0	0
CB	200	11	0	24	2 (2)[f,g]	0
CE	200	10	0	16	1 (1)[h]	3[ad,al,ar]
DA	160	25	30	16	0	0
DB	160	25	20	16	0	0
DD	160	25	10	28	4 (2)[i,j,k,y]	0
EA	200	25	55	16	0	0
EB	200	25	40	20	1[l]	1[ae]
ED	200	25	20	16	3[m,n,z]	1[af]
FA	230	25	100	19	0	0
FB	230	25	65	18	0	0
FD	230	25	30	12	2 (1)[o,p]	0
GA	260	20	100	16	0	0
GB	260	20	65	16	0	1[ai]
GD	260	20	30	4	2 (1)[q,r]	1[aj]
HB	260	25	120	24	1[s]	1[ak]
HD	260	25	95	27	1 (1)[t]	0
IA	300	25	190	16	0	3[ah,am,an]
IB	300	25	165	16	3 (2)[u,v,w]	1[ao]
IE	300	25	180	32	1[x]	4[ag,ap,at,au]
Total				472	26 (13)	22

Table 3: Comparison of NoD Times
From 0.7 ATA PO₂ Tables vs Tested "A" profile

Depth fsw	NoD Limit 0.7 PO ₂ min	Tested NoD Profiles "A" : 1.3 PO ₂				
		NoD Time min	Time Gain min (%)	Dives	DCS	Marg
120	18	27	9 (50)	24	1	2
160	8	13	5 (63)	24	1	2
200	6	9	3 (50)	16	0	0

Table 4: Comparison of TST
From 0.7 ATA PO₂ Tables vs Tested "A" profile

Depth fsw	Bottom Time min	0.7 PO ₂ Table TST min	Tested Decompression Profiles "A" : 1.3 PO ₂				
			TST min	Reduction in TST min (%)	Dives	DCS	Marg
160	25	57	30	27 (47)	16	0	0
200	25	101	55	46 (46)	16	0	0
230	25	169	100	69 (41)	19	0	0
260	20	164	100	64 (39)	16	0	0
300	25	410	190	220 (54)	16	0	3
Totals				Average (45)	83	0	3

Table 5: Comparison of first stop depth
from 0.7 ATA PO₂ Tables versus Tested
"A" profiles

Depth fsw	BOT min	First Stop Depth (fsw)	
		0.7 Table	"A" Profile
160	25	40	40
200	25	80	60
230	25	100	80
260	20	120	80
260	25	130	100
300	25	160	120

Table 6: Comparison of TST
From 0.7 ATA PO₂ Tables vs Tested "D" profiles

Depth fsw	Bottom Time min	0.7 PO ₂ Table TST min	Tested Decompression Profiles "D" : 1.3 PO ₂				
			TST min	Reduction in TST min (%)	Dives	DCS (Type II)	Marg
160	25	57	10	47 (82)	28	4 (2)	0
200	25	101	20	81 (80)	16	3	1
230	25	169	30	139 (82)	12	2 (1)	0
260	20	164	30	134 (82)	4	2 (1)	1
260	25	267	95	172 (64)	27	1 (1)	0
Totals				Average (78)	87	12 (5)	2

Appendix 1: Physical Attributes of Subjects

Diver	DOB	Height (in)	Weight (lb)	# of Dives	DCS outcomes	Marginal outcomes
1	29 Feb 68	69	182	1	1	0
2	18 Sep 64	72	180	1	0	0
3	19 Sep 59	70	195	3	0	0
4	08 Sep 57	72	178	6	1	2
5	01 Sep 57	60	180	6	0	0
6	26 Feb 61	75	200	4	2	0
7	03 Aug 62	68	183	4	0	0
8	31 Jul 61	68	178	1	0	0
9	19 Mar 68	69	155	4	0	0
10	01 Sep 61	70	170	6	2	0
11	22 Oct 66	72	165	6	0	0
12	29 May 65	72	175	1	0	0
13	04 Dec 62	74	165	2	0	1
14	12 Jul 57	70	158	1	0	0
15	16 Oct 64	69	160	5	0	0
16	18 Dec 64	68	170	19	1	0
17	10 Mar 60	72	172	1	0	0
18	04 Mar 65	73	230	9	2	1
19	03 Dec 64	70	180	2	0	0
20	19 Jan 61	67	170	12	0	0
21	08 Aug 63	69	175	21	0	2
22	15 Oct 64	66	160	4	0	2
23	06 Feb 64	67	190	4	0	0
24	04 Sep 61	69	173	1	1	0
25	17 Nov 63	69	170	4	0	0
26	20 Nov 54	69	160	21	0	0
27	08 Aug 64	70	183	4	0	0
28	25 Dec 60	70	190	4	0	0
29	01 Jul 59	70	200	2	0	0
30	23 Jan 61	75	268	6	0	0
31	18 Jun 69	67	150	3	0	0
32	04 May 63	69	200	4	1	0
33	11 Jan 62	71	178	6	1	0
34	18 Nov 58	72	184	2	0	0
35	12 Aug 61	68	190	20	0	1
36	01 Dec 69	70	180	4	0	0
37	16 Jul 65	70	163	2	0	0
38	19 Jan 62	74	190	4	0	0
39	15 Oct 64	69	165	5	0	0
40	08 Oct 62	67	160	6	0	0
41	11 Nov 64	70	190	4	0	0

42	31 Oct 67	71	185	16	1	1
43	23 Jun 53	73	205	3	2	1
44	21 Aug 58	69	190	2	0	0
45	24 Nov 65	69	165	6	0	0
46	15 Oct 69	72	175	5	0	0
47	02 Sep 60	72	165	1	0	0
48	26 Aug 59	71	187	4	1	0
49	01 May 67	67	170	6	0	1
50	13 Sep 67	72	180	4	1	0
51	19 Sep 58	73	210	4	0	1
52	23 Nov 58	66	155	7	0	1
53	15 Jan 55	66	146	10	2	1
54	23 Jun 63	75	216	23	0	1
55	04 Nov 72	69	165	2	0	0
56	27 Apr 56	72	205	2	1	0
57	23 Jun 63	73	205	4	0	1
58	27 Nov 55	67	172	20	1	1
59	20 Oct 64	74	208	15	1	0
60	26 Sep 65	70	178	5	0	0
61	13 Feb 60	66	170	4	1	1
62	19 Mar 62	69	160	18	0	0
63	06 Dec 63	72	216	7	1	0
64	07 Jan 57	70	150	3	0	0
65	07 Feb 70	68	150	6	0	0
66	29 Dec 72	71	170	4	0	0
67	30 Jul 71	69	155	7	0	0
68	27 May 67	73	208	3	1	0
69	19 Oct 64	75	228	2	0	1
70	21 Oct 59	70	176	1	0	0
71	31 Oct 61	74	185	13	0	0
72	06 Jul 60	72	220	4	0	0
73	29 Jul 65	69	150	2	0	0
74	04 Feb 62	71	177	9	1	1
75	13 Jul 60	68	142	3	0	1
76	27 Jan 60	74	215	8	0	0
77	20 Oct 60	69	170	2	0	0
78	21 Feb 67	71	180	12	0	0

Appendix 2: Chronological Record of Dives.

The first letter in the dive name corresponds to the dive series e.g. dive series *B* involved NoD dives at 160 fsw while dive series *E* involved decompression dives at 200 fsw with 25 min of bottom time. Second letter in the dive name denotes a specific position in the three tier design as shown in Fig 1. Numbers in the dive name denote replication count. The Diver (Symptom) column contains diver number and outcome case reference described in Appendix 4 where a single letter designation denotes a DCS outcome while double letters denote a marginal outcome.

Date YY/mm/dd	Time hh:mm	Dive Name	Depth (fsw)	BOT (min)	TST (min)	Diver (Symptom) -----		Water Temp °F
95/02/13	10:00	AA01	120	27	0	4	54	74
95/02/14	10:22	AA02	120	27	0	22 (aq)	34	69
95/02/16	10:01	AA03	120	27	0	16	21	62
95/02/21	10:03	AA04	120	27	0	25	33	61 (a)
95/02/23	09:52	AA06	120	27	0	11	45	64
95/02/27	09:28	AA07	120	27	0	25	40	53 (aa)
95/02/28	09:28	AB01	120	32	0	11	43 (ab)	63
95/03/01	09:26	AB02	120	32	0	10	62	69 (av)
95/03/01	09:27	AB03	120	32	0	21	42	56
95/03/06	09:31	AB04	120	32	0	11	43 (b)	49
95/03/07	09:36	AB05	120	32	0	26	35	56 (c)
95/03/08	09:26	AE01	120	30	0	16	53	62
95/03/09	09:25	AE02	120	30	0	11	45	58
95/03/13	09:25	AE03	120	30	0	10	11	49
95/03/14	09:24	AE04	120	30	0	35	53	51
95/03/14	10:58	AE05	120	30	0	16	40	51
95/03/20	10:15	BA01	160	13	0	11	35 (ac)	45
95/03/21	09:22	BA02	160	13	0	22	26	58
95/03/22	09:52	BA03	160	13	0	21	53	64
95/03/23	10:04	BA04	160	13	0	10 (d)	16	40

Appendix 2 (cont.)

Date yy/mm/dd	Time hh:mm	Dive Name	Depth (fsw)	BOT (min)	TST (min)	----- Diver (Symptom) -----	Water Temp °F					
95/03/27	09:37	BA05	160	13	0	21	63	26	21	63	68	46
95/03/28	09:28	BA06	160	13	0	18	40	22	18	54	54	46
95/03/30	09:24	BB01	160	16	0	53	65	58	53	67	67	45
95/04/03	09:22	BB02	160	16	0	34	65	63	34	67	67	46
95/04/04	08:50	BB03	160	16	0	35	58	44	35	62	62	46
95/04/05	09:50	BB04	160	16	0	16	21	18	16	53	53	46
95/04/06	09:23	BD01	160	18	0	54	67	65	54	68 (e)	68 (e)	46
95/04/17	09:40	CA02	200	9	0	19	65	37	19	67	67	46
95/04/19	09:22	CA04	200	9	0	10	59	53	10	74	74	49
95/04/20	09:25	CA05	200	9	0	26	65	54	26	67	67	49
95/04/24	09:40	CA06	200	9	0	19	67	65	19	71	71	49
95/04/25	10:30	CB01	200	11	0	10	48	35	10	58	58	50
95/04/26	09:45	CB02	200	11	0	20	40	24 (f)	20	41	41	45
95/04/27	09:28	CB03	200	11	0	26	54	51	26	67	67	43
95/05/01	09:17	CB04	200	11	0	31	41	35	31	44	44	42
95/05/02	09:16	CB05	200	11	0	18	26	21	18	71	71	43
95/05/03	09:10	CB06	200	11	0	20	43 (g)	33	20	47	47	45
95/05/09	09:27	CE01	200	10	0	31	51 (ad)	41	31	63	63	45
95/05/10	09:33	CE02	200	10	0	22 (al)	42	26	22 (al)	59	59	44
95/05/11	09:26	CE03	200	10	0	4	48	16	4	54	54	45
95/05/15	11:06	CE04	200	10	0	31	42 (ar)	41	31	63 (h)	63 (h)	45
95/05/30	11:04	DA01	160	25	30	35	52	48	35	58	58	55
95/05/31	08:46	DA02	160	25	30	26	59	42	26	71	71	56
95/06/01	09:38	DA03	160	25	30	7	39	23	7	54	54	55
95/06/05	08:57	DA04	160	25	30	7	50	39	7	66	66	55

Appendix 2 (cont.)

Date yy/mm/dd	Time hh:mm	Dive Name	Depth (fsw)	BOT (min)	TST (min)	----- Diver (Symptom) -----	Water Temp °F
95/06/06	09:03	DB01	160	25	20	16	55
95/06/08	08:08	DB03	160	25	20	26	55
95/06/08	10:07	DB04	160	25	20	7	55
95/06/12	10:21	DB05	160	25	20	23	55
95/06/13	08:40	DD01	160	25	10	7	??
95/06/14	08:07	DD02	160	25	10	10 (i)	50
95/06/15	09:15	DD04	160	25	10	23	51
95/06/29	09:40	DD05	160	25	10	20	51
95/06/29	11:33	DD06	160	25	10	21	51
95/07/05	09:36	DD07	160	25	10	26	51
95/07/06	09:38	DD08	160	25	10	20	52
95/07/20	09:45	EA02	200	25	55	26	54
95/07/25	10:17	EA03	200	25	55	21	54
95/08/01	09:53	EA04	200	25	55	16	55
95/08/02	09:38	EA05	200	25	55	4	54
95/08/29	08:28	EB01	200	25	40	26	55
95/08/29	12:09	EB02	200	25	40	21	55
95/09/05	09:49	EB03	200	25	40	4 (ae)	54
95/09/06	09:54	EB04	200	25	40	20	54
95/09/07	12:45	ED01	200	25	20	27	52
95/09/11	09:44	ED02	200	25	20	4 (m)	52
95/09/12	08:20	ED03	200	25	20	20	53
95/09/12	10:27	ED04	200	25	20	1 (n)	53
95/09/13	13:07	EB05	200	25	40	52	55
95/09/19	09:27	FA01	230	25	100	16	58
95/09/20	08:20	FA02	230	25	100	35	55
95/09/20	12:05	FA03	230	25	100	20	56

Appendix 2 (cont.)

Date yy/mm/dd	Time hh:mm	Dive Name	Depth (fsw)	BOT (min)	TST (min)	----- Diver (Symptom) -----	Water Temp °F
95/09/21	09:29	FA04	230	25	100	42	59
95/09/25	09:07	FA05	230	25	100	16	54
95/09/26	08:40	FB01	230	25	65	35	55
95/09/26	11:48	FB02	230	25	65	42	55
95/09/27	08:50	FB03	230	25	65	21	54
95/09/28	08:50	FB04	230	25	65	6	55
95/09/28	11:53	FB05	230	25	65	18	55
95/10/02	08:53	FD01	230	25	30	18	53
95/10/03	08:26	FD02	230	25	30	6(p)	51
95/10/03	11:21	FD03	230	25	30	16	51
95/10/10	08:53	GA01	260	20	100	5	56
95/10/11	08:06	GA03	260	20	100	30	57
95/10/11	12:51	GA04	260	20	100	21	56
95/10/12	08:31	GA05	260	20	100	42	56
95/10/13	08:31	GB01	260	20	65	5	59
95/10/16	08:49	GB02	260	20	65	21(ai)	58
95/10/16	11:44	GB03	260	20	65	5	59
95/10/17	08:32	GB04	260	20	65	25	58
95/10/17	11:30	GD01	260	20	30	18(q)	55
95/10/19	08:33	HB01	260	25	120	16	65
95/10/19	12:11	HB02	260	25	120	6(s)	65
95/10/20	08:11	HB03	260	25	120	4(ak)	64
95/10/20	11:52	HB04	260	25	120	3	65
95/10/23	08:13	HB05	260	25	120	54	65
95/10/24	08:08	HB07	260	25	120	5	65
						51	52
						38	60
						59	74
						52	55
						26	62
						20	27
						36	38
						54	59(o)
						30	36
						35	38
						6	16
						54	58
						26	62
						72	75
						16	18
						28	32
						16	42
						35	38
						30	58(r)
						17	26
						29	36
						21	62
						30	35
						57	76
						29	62
						75(aj)	71
						54	54
						42	42
						76	76
						78	78
						78	78
						71	71

Appendix 2 (cont.)

Date yy/mm/dd	Time hh:mm	Dive Name	Depth (fsw)	BOT (min)	TST (min)	----- Diver (Symptom) -----	Water Temp °F
95/10/24	12:10	HD01	260	25	95	2	62
95/10/25	09:35	HD03	260	25	95	16	61
96/02/07	11:16	HD04	260	25	95	9	61
96/02/13	08:42	HD06	260	25	95	9	61
96/02/14	09:38	HD07	260	25	95	21	60
96/02/15	08:38	HD08	260	25	95	16	60
96/02/20	08:29	HD09	260	25	95	15	60
96/02/27	09:22	IA01	300	25	190	21 (ah)	65
96/02/28	09:00	IA02	300	25	190	28	65
96/02/29	09:24	IA03	300	25	190	15	67
96/03/01	08:30	IA04	300	25	190	18 (an)	66
96/03/04	08:52	IB01	300	25	165	15	67
96/03/05	08:35	IB02	300	25	165	3	68
96/03/06	08:58	IB03	300	25	165	13	65
96/03/07	09:02	IB04	300	25	165	21	65
96/03/11	08:43	IE01	300	25	180	15	69
96/03/18	08:35	IE02	300	25	180	5	67
96/03/25	08:52	IE03	300	25	180	8	67
96/04/01	08:44	IE04	300	25	180	5	67
96/04/02	08:48	IE05	300	25	180	25	66
96/04/10	08:49	IE07	300	25	180	57 (ap)	67
96/04/12	08:20	IE08	300	25	180	3	67
96/04/15	09:12	IE09	300	25	180	14	67
						21	
						28	
						74 (v)	
						32 (w)	
						46	
						46	
						46	
						13 (ag)	
						61 (au)	
						74	
						58 (at)	
						9	
						33 (x)	
						28	

[illegible]

Diver	Dive Name (Symptom)					
23	DA03	DB01	DB05	DD04		
24	CB02 (f)					
25	AA04	AA07	GB04	IE05		
26	AB05	BA02	BA05	CA05		DA02 HB01
	DB03	DD01	DD07	EA02		
	HD03	HD04	HD07	IA01		
27	ED01	ED03	FA03	FB04		
28	GB02	IA02	IB04	IE09		
29	HB02	HB07				
30	FB04	FD02	GA03	GD01	HB04	HD01
31	CB04	CE01	CE04			
32	GB02	IA02	IB04 (w)	IE04		
33	AA04	CB06	EB01	HD09	IA04	IE08 (x)
34	AA02	BB02				
35	AB05	AE04	BA01 (ac)	BB03	CB01	DA01 FA02 DB01 FB01
	DD07	EA03	EA04	EB02	EB03	
	FD03	GB01	GB04	HB04		
36	FB05	FD02	GA01	HB02		
37	AA04	CA02				
38	FA05	FB05	FD03	GB04		
39	DA03	DA04	DB04	DB05	DD04	
40	AA03	AA07	AE05	BA04	BA06	CB02
41	CB02	CB04	CE01	CE04		
42	AB03	BA02	CE02	CE04 (ar)	DA02	DD02 (y) HB02
	EB04	FA04	FB02	GA05	GB03	EA02 HD08 EA05 HD09
43	AB01 (ab)	AB04 (b)	CB06 (g)			
44	BB03	CB04				
45	AA06	AB01	AB04	AE02	AE03	BA01
46	HD01	IB01	IE01	IE02	IE03	
47	CB06					

Appendix 3 (cont.)

Diver	Dive Name (Symptom)		-----	
48	CB01	CE03	DA01	DD07 (k)
49	AA07	AB03	AB04	AE02
50	DA04	DB04	DB05	DD04 (j)
51	AA06	CB03	CE01 (ad)	FA04
52	DA01	DB03	EB05	FA04
53	AA07 (aa)	AE01	AE04	BA03
	EB04 (l)	HD04 (t)		
54	AA01	BA06	BD01	CA05
	DD05	DD08	EA02	EA05
	GA03	HB01	HB05	HD08
55	FA01	FB02		
56	AB03	AB05 (c)		
57	AA01	HB05	IB03	IE07 (ap)
58	AA02	AE02	AE04	BA02
	DB01	DD01	DD05	EA03
	GA03	GD01 (r)	IB03	IE07 (at)
59	CA04	CE02	DA02	DD06
	ED01	ED02	FA04	FB01
60	EB01	ED01	ED02	FA02
61	AA04 (a)	HD06	IE01	IE05 (au)
62	AA03	AB02	AE01	BA03
	EB03	EB05	FA02	FB03
	HB07	IB01		
63	AB01	BA05	BB02	CE01
64	AA06	AB02	BA03	GB04 (h)
65	BB01	BB02	BD01	GB04
66	DA04	DB04	DB05	CA05
67	BB01	BB02	BD01	CA06
				CB03
				EA02
				IE08
				CA04
				EA02
				DB03
				FD01
				IE05
				DA01
				FD02 (ah)
				EB02
				DD06
				HB03
				HD03 (al)
				CA06
				CA06
				CB03

Appendix 3 (cont.)

Diver	Dive Name (Symptom) -----									
68	AB05	BA05	BD01 (e)							
69	AA02	AB02 (av)								
70	IA01									
71	CA06	CB05	DA02	DD06	DD07	EA05	EB03	EB05		
	FD01	GA04	HB07	IA03	IE02					
72	FA01	GA05	IA04	IE03						
73	DD02	DD05								
74	AA01	CA04	EB01	ED02 (af)	FB01	HD07	IA02	IB04 (v)		
	IE07									
75	GA05	GD01 (aj)	HD01							
76	FB01	GA03	HB03	HB05	HD07	IA03	IB02	IE07		
77	IA02	IE05								
78	ED03	FA02	FB02	GA05	GB02	HB04	HB05	HD04		
	HD08	IA01	IB02	IE09						

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Appendix 4: DCS Case Descriptions

Case: a

Subject #61

Dive Date: 21 Feb 95

Dive Profile: AA04

Reached Surface: 1106

Treatment Date: 22 Feb 95

NMRI DMO Diagnosis: DCS Type I

Diver was asymptomatic at the 10 minute and 2 hour checks. When he awoke the following morning he had an aching pain in his left hand, specifically in the MCP and PIP joints of the index to ring fingers (2,3 and 4). He called the dive watch office and was examined by a DMO at 0615; pain was described as 3/10, non-radiating and increased with movement. USN TT6 began at 0656 (no extensions). Pain decreased after 3 minutes and was almost completely resolved after 17 minutes. Complete relief of symptoms without residual upon completion of treatment.

Case: b

Subject #43

Dive Date: 06 Mar 95

Dive Profile: AB04

Reached Surface: 1020

Treatment Date: 06 Mar 95

NMRI DMO Diagnosis: DCS Type II

Diver was asymptomatic at the 10 min post-dive check. While showering (15-20 minutes after surfacing) he noted the rapid onset of warmth in his right lower back that radiated from his buttock and back of thigh to the back of his right knee. The pain was not exacerbated by movement, but increased in severity and he developed weakness of his hip with the increasing pain. The diver stated that he had never had a similar event. (note: during his pre-dive evaluation this diver reported history of right hip pain after last dive, but the pain was dissimilar to present complaint - no treatment). No additional paresthesia or other sensory features noted; slight weakness of hip flexion on exam.

The symptoms worsened and the DMO began chamber recompression treatment prior to completion of a full neurological exam. Recompression began at 1044 with a hold at 10 fsw to allow the diver to clear his ears. The diver was recompressed on air to 40 fsw, and reported dramatic improvement and full relief at 60 fsw. A complete neurological exam at one hour into recompression was normal. Diver was asymptomatic upon completion of USN TT6 (no extensions) and a full neuro exam was unremarkable. (Note: diver remarked upon surfacing that his right leg might have been slightly weaker during the recompression neuro check when compared to the neuro exam after surfacing from treatment). Slight injection of the right Tympanic Membrane indicated mild barotrauma, normal movement with Valsalva. All post-treatment checks were normal and patient remained asymptomatic.

Case: c
Subject #56
Dive Date: 07 Mar 95
Dive Profile: AB05
Reached Surface: 1023
Treatment Dates: 07 & 13 Mar 95
NMRI DMO Diagnosis: DCS Type II

Immediately upon surfacing, while still immersed, diver repeatedly signaled the other dive team members to go back down, apparently confusing the hand signals to exit the water; he had no recall of this incident later. He then appeared confused in communicating with the tenders on the surface while undressing. Within 5 minutes after surfacing the diver noted a "tingling" sensation in his left medial ankle, rapidly followed by a feeling of "fatigue" and fullness in his lower back, over the sacroiliac area. He walked into the next chamber, said he felt "different" and wanted to sit. A cursory neuro exam was unremarkable except generalized hyperreflexia but consistent with the pre-dive exam. The diver then reported a "shooting pain" and paresthesia down his right buttock and leg during a right Babinski; Babinski was downgoing bilaterally. Diver reported that the buttock pain was getting worse and that he also felt heat and tingling over the region that was progressing to the back of both upper thighs. He immediately laid down and said that his legs were feeling numb throughout. Neuro exam by the DMO elicited normal hip flexor strength on the left, but completely absent flexor strength on the right. He was put on 100% oxygen at 1032 and quickly recompressed to 60 fsw. All symptoms completely resolved within 5 min of reaching 60 fsw. Neuro exams by the DMT upon reaching 60 fsw and 30 and 60 minutes later were non-focal. A USN TT6 with no extensions was completed, diver surfaced asymptomatic. Post-treatment and 24-hour neuro exams were normal. At 1100 on 09 March, diver evaluated for complaint of "fatigue" and a "feeling of lactic acid build-up" in his lower back. He also reported having worked out very hard on the Nautilus machine a couple of days before and that this may be secondary to that workout. Physical and neuro exams were completely normal. DMO diagnosis was lower back fatigue, with conservative, non-recompression management.

On 13 March the diver again sought medical attention, and complained of a fluctuating sensation of "cold" in his right foot and that his right leg felt "different". Exam revealed patchy alteration of sensation to pin prick on right leg (lateral thigh, lateral calf) in L5 distribution. Remainder of neuro exam was normal. He was retreated on a USN TT6 (began at 1145) without extensions. He reported subjective relief during recompression and complete relief with normalization of sensory exam near the end of the 3rd oxygen period at 60 fsw. Ten minutes after surfacing from treatment he reported feeling normal and a neuro exam was normal. One hour post-treatment he reported mild sense of coldness and tingling in distal right toes, but an exam remained normal. He also had a mild end-inspiratory "catch" with deep inspiration, but lungs were clear. The attending DMO diagnosed residual Type II DCS symptoms, with near complete resolution after retreatment, and mild pulmonary oxygen toxicity. Diver reported 14 Mar for follow-up exam with no complaints, and complete resolution of the sensory changes in his feet. A neuro exam was normal and all previously affected areas were equally sensitive to soft touch and pinprick. The diver was determined to have full resolution of DCS with no residual symptoms.

Case: d
Subject #10
Dive Date: 23 Mar 95
Dive Profile: BA04
Reached Surface: 1030
Treatment Date: 23 Mar 95
NMRI DMO Diagnosis: DCS Type I

At the 10 minute post-dive check the diver reported very slight right elbow pain but attributed it to the cold (he had noted similar pain after a previous dive that had resolved quickly with rewarming). A detailed sensory and motor neurological exam was completely normal. About 20 minutes post-dive he noted left knee pain. The pain became constant over the following 5 minutes, 3-4/10 in intensity, and worsened with deep knee bends. He stated that this pain was "not normal" and "not present before the dive". Another neurological exam was again completely normal, as was a detailed sensory and motor exam of the left leg.

The diver was recompressed on a USN TT5 at 1108 and had complete relief within 3 minutes at 60 fsw; he surfaced asymptomatic and had a normal neurological exam. He remained asymptomatic and at the 22 hour post-treatment exam reported only mild bilateral ear pain that was relieved with Valsalva. No residual symptoms.

Case: e
Subject #68
Dive Date: 06 Apr 95
Dive Profile: BD01
Reached Surface: 0955
Treatment Date: 06 Apr 95
NMRI DMO Diagnosis: (likely?) DCS Type II

Diver was asymptomatic upon surfacing and at the 10 minute check. Approx. 25 minutes post-dive he complained "it feels like someone punched me in the stomach". Over the next 20-30 seconds the pain progressed to include the lumbar region and was described as 10/10 in severity with radiation around both sides. Diver denied limb weakness or sensory changes and was immediately recompressed (1031) to 60 fsw on oxygen. He reported complete relief of symptoms during descent and remained asymptomatic at depth. A complete neuro exam at depth was normal. Subject was treated on USN TT6 with no extensions, tolerated it well, surfaced asymptomatic and remained asymptomatic. Two hour and 18 hour exams after treatment were normal.

Case: f
Subject #24
Dive Date: 26 Apr 95
Dive Profile: CB02
Reached Surface: 1016
Treatment Date: 26 Apr 95
NMRI DMO Diagnosis: likely DCS Type II

Diver was asymptomatic upon surfacing and at the 10 minute check, but approx. 2 mins later he noted the onset of deep lower sacral pain. An immediate but brief neuro exam of the lower trunk was normal, but during the exam he noted the pain rapidly increasing and within ~2-3 minutes it reached 7-8/10 in severity and began radiating down the back of his left leg into the calf. He was able to walk to the recompression chamber without assistance or obvious gait abnormality. No frank neurological deficit was found, but the exam was rushed due to diver distress.

At 1036 diver was recompressed to 60 fsw. During descent he noticed that the radiating quality of the pain resolved and the localized (sacral/left buttock) pain decreased to 2-3/10. By the end of the first oxygen period he noted complete relief of all symptoms. TT6 (no extensions) was completed without difficulty. Neuro exam 15 minutes after treatment was completely normal, as were the exams at 2 hours and 16 hours post treatment.

Case: g
Subject #43
Dive Date: 03 May 95
Dive Profile: CB06
Reached Surface: 0935
Treatment Dates: 03, 04, 05 May 95
NMRI DMO Diagnosis: DCS Type II

No symptoms at the 10 minute check, but approximately 5 min later the subject was mildly confused when removing his wet suit - the DMO told him that he needed to remove his booties, but still tried to get off the wet suit; he also complained of bilateral back pain radiating around the sides to the level of ~ T4 (6-7/10 severity). A detailed neuro exam was not completed at that time because he was immediately taken for treatment. Subject reported complete relief during descent. A complete neuro exam was performed at depth and although he indicated he needed to "concentrate really hard" for the heel-to-toe test [*sic*], everything else was normal. A USN TT6 was completed with no extensions.

On 04 May the subject reported patchy paresthesia from approx. the T-7 level down into the lower extremities. He was again treated on a USN TT6, this time without improvement. On the morning of 05 May the diver reported some overnight improvement, but the DMO notes indicate decreased sensation remaining bilaterally on the lower extremities. The neuro and physical exams were otherwise normal. Subject was treated again on a USN TT6 with near complete resolution of paresthesias except the right big toe and a patch (approx. 10 cm) on the right lateral thigh. The subject also reported a mild uncomfortable sensation with deep respiration.

Case: g (continued)

During the morning of 06 May the diver noted a general sense of euphoria with persistence of the right big toe paresthesia. That afternoon he reported a gradual onset of pain, and a warm sensation down the back of his left leg. This pain subsided after work and there was no further recurrence of symptoms. No treatment. The follow-up examination on 08 May reported no residual symptoms and non-focal neuro exam.

Case: h

Subject #63

Dive Date: 15 May 95

Dive Profile: CE04

Reached Surface: 1135

Treatment Date: 15 May 95

NMRI DMO Diagnosis: Acute neurologic DCI with cerebral features

Diver was asymptomatic upon surfacing and through the 10 minute clean time. Approx. 15-20 after surfacing he complained of an ill-defined inability to concentrate and a sensation of generalized weakness. He became increasingly anxious and tried to stand but was unable to do so without support. He was immediately assisted to the chamber to begin treatment at 1157 and was recompressed to 60 fsw on oxygen. He had no recall of the questions that had been asked of him in sickbay, or of being helped to the chamber. During recompression he had a brief sensation of pain in his lower back, radiating "like a lightening bolt" down the back of both legs. By 60 fsw his sensorium had cleared and all symptoms had resolved.

His neurological exam while on bottom was normal; an initial memory test resulted in recall of 1 of 3 items but cleared with subsequent testing. After 1 hour at 60 fsw he was re-examined by the DMO and found to be anxious but without neurological signs. USN TT6 (without extensions) was completed. Neurological exam after treatment was normal except for absent left-sided abdominal reflexes and slight asymmetry in knee reflexes (L<R). The diver remained asymptomatic 24-hours post-treatment except for some residual anxiety. No further treatment was warranted.

Case: i
Subject #10
Dive Date: 14 Jun 95
Dive Profile: DD02
Reached Surface: 0927
Treatment Date: 14 Jun 95
NMRI DMO Diagnosis: DCS Type I

Diver surfaced asymptomatic, but 13 minutes later he noted a "muscular tightness" in his left hip (diver thought it might be secondary to shivering). The "tightness" or pain was 2/10 in intensity, non-radiating, and lasted approx. 2 minutes. A neurological exam was normal, including detailed motor and sensory exam of the left hip and lower extremities. These symptoms resolved and he remained asymptomatic until 2 hours after surfacing (1125) when he complained of a deep left hip pain that radiated postero-laterally into the left knee. Over the next 5 minutes the pain became localized to the left knee with the left hip becoming asymptomatic; left knee pain was non-radiating, slowly increasing (4/10 just prior to treatment), not affected by position or movement. Neurological exam was completely normal. The diver reported that he had been bent in the same knee on 23 Mar 95 (82 days earlier) with similar pain.

Diver was recompressed to 60 fsw on oxygen at 1151 and reported complete relief approx. 2 minutes into the first oxygen period. Neurological exam was completely normal. USN TT6 was completed without extensions and another neurological exam upon surfacing from treatment was normal. Diver remained asymptomatic 2 hours post-treatment.

Case: j
Subject #50
Dive Date: 15 Jun 95
Dive Profile: DD04
Reached Surface: 1012
Treatment Date: 16 Jun 95
NMRI DMO Diagnosis: DCS Type II

Diver surfaced and remained asymptomatic for 24 hours. About 28 hours after the dive he presented complaining of lower back pain that he reported as having started approx. 7 hours after surfacing (but presumably did not previously report at the 10 min, 2 hr or 24 hr checks). The ache was also associated with hypoesthesias in the same area as the pain. A complete neurological exam was normal except for an approx. 10% sensory deficit in the left paravertebral (L₄-L₅) region subjectively to light touch over a 2x3 cm area. No other deficits except a questionable decreased sensation in left lower extremity 5th digit. Sensation to sharp/dull was intact throughout. The diver was recompressed to 60 fsw on oxygen at 2124 (16 Jun 95) and reported complete relief of symptoms in less than 10 minutes. Neurological exams during and after treatment were completely normal. USN TT6 completed (no extensions) and diver remained asymptomatic.

Case: k
Subject #48
Dive Date: 05 Jul 95
Dive Profile: DD07
Reached Surface: 1045
Treatment Dates: 10, 11, 16, 17, 18 Jul 95
NMRI DMO Diagnosis: DCS Type II

The diver surfaced and was cleared by DMO through the 10-minute and 2-hour checks. However, he reported that the last time he felt completely fine was prior to the dive. Upon surfacing he had some bilateral buttock pain (1/10) that increased with activity and palpation, but he reported that this pain was typical for him after riding bicycles during chamber dives. He also complained of some tingling sensation in his hands and forearms which he considered to be secondary to the cold dive; tingling had decreased by the 2-hour check. The diver maintained that he was not bent and did not want to be treated. The 2-hour post-dive neurological exam was normal except for a "possible subtle hip flexor weakness" on the right side. Re-examination with a DMO/neurologist revealed normal right hip strength.

At the 24-hour check (Thursday 06 Jul 95 @ 0700) the diver reported that he was fine except for some fatigue. He was next re-examined on Monday, 10 Jul 95 when he reported that he had several difficulties during the weekend and wanted to withdraw from the dive study. With prompting he described a number of "strange mood states", feelings of euphoria, and had gotten lost 3 times during his drive to South Carolina. He also reported decreased attention, trouble speaking, difficulty finding words and remembering past events. His wife confirmed that he had acted strangely: laughing inappropriately, night sweats and violent nightmares, all since completing the 5 Jul 95 dive. Fellow divers also reported that he was not himself and had been acting strangely. A neurological exam was normal except for a subjective tingling sensation in his hands and a sense that he was thinking correctly. He was treated with recompression (10 Jul 0805) on a USN TT6 (one extension) with a slight improvement of his tingling sensation while at 60 fsw on oxygen but otherwise no change in his subjective mental status changes.

He was referred to Neurology at NNMC and admitted for diagnostic testing. An EEG and MRI were obtained and found to be normal. No conclusive neurologic signs were found. A borderline Babinski was noted in his right foot, but it may have existed prior to the dive and was not considered by the Neurology staff to indicate any major neurologic sequela. He was scheduled for a neuropsychiatric exam 6 weeks later. He was treated a second time on the following day (11 Jul 95 @ 1038) using a modified Kindwall protocol (45 fsw for 90 min); no changes in symptoms.

[This diver was also participating in a developmental vaccine trial in the Infectious Disease Department. He had given 30 cc blood and received an oral candidate (placebo or adjuvant not known) two weeks prior to the dive. (*Campylobacter* protocol). It was not considered that this contributed to his current symptoms.]

Case: I
Subject #53
Dive Date: 06 Sep 95
Dive Profile: EB04
Reached Surface: 1143
Treatment Dates: 07 Sep 95
NMRI DMO Diagnosis: DCS Type I

Diver surfaced and remained asymptomatic through the 10 min and 2 hr checks. Approx. 2 hr 45 min after surfacing he noted a feeling of euphoria followed later in the afternoon by fatigue. He later recalled that in the afternoon (~1400) he noted increased forgetfulness. That evening while working on his motorcycle he had trouble remembering where he put his tools and noted a decreased ability to concentrate; felt "disoriented: and extreme fatigue. While taking a hot shower approx. 2200 he noted the onset of a deep, aching bilateral shoulder pain that was different than his chronic shoulder discomfort. He also noticed a neck "stiffness" and low back pain. He took 800 mg ibuprofen and slept without difficulty. The following morning he noticed a pain in his left arm radiating to the palm; initially the pain only occurred with weight-bearing but later recurred as a "shooting" pain while resting. The shoulder, neck and low back pain were still present and while he felt better overall than the previous night, he did not feel he was back to baseline. He presented with these complaints at the 24-hour post-dive evaluation. His physical exam revealed mild lumbar paraspinal spasm (L>R), without tenderness in any of the painful areas. Neurological exam was normal. He was treated on a USN TT6 (0813, 07 Sep) and noted no significant change in symptoms at 60 fsw. After about 1 hr of recompression he reported complete resolution of his left arm and hand discomfort and neck stiffness, decreased shoulder discomfort, and a decrease in general malaise. After treatment he reported feeling much improved: his shoulder discomfort had returned to baseline, no recurrence of the left arm/hand discomfort, and malaise had resolved. Post treatment checks were unremarkable.

Case: m
Subject #4
Dive Date: 11 Sep 95
Dive Profile: ED02
Reached Surface: 1059
Treatment Date: 11 Sep 95
NMRI DMO Diagnosis: DCS Type I

Within 2 minutes of surfacing the diver experienced pain in his left elbow. The pain was initially intermittent, but rapidly progressed to a constant, dull ache, 3/10 intensity, unaffected by movement or posture. No neurological or other signs or symptoms during examination in the chamber. Examination of the affected arm was unremarkable. The attending DMO recommended treatment on a USN TT5, but the Master Diver decided on a USN TT6 which was started at 1113. Diver reported complete relief of symptoms during recompression and a complete neurological exam while at depth was normal. At the 24-hour post-treatment check the diver reported mild lung discomfort attributed to oxygen breathing and moderate fatigue. No other residual symptoms.

Case: n
Subject #1
Dive Date: 12 Sep 95
Dive Profile: ED04
Reached Surface: 1141
Treatment Date: 12 Sep 95
NMRI DMO Diagnosis: DCS Type I

Diver noted onset of low grade left shoulder pain just prior to surfacing; pain increased in severity throughout the physical evaluation immediately after surfacing. The pain peaked (8/10), was described as "severe pain" and was then present in both shoulders; pain was unaltered by movement or palpation. A partial neurological exam was completed without report of numbness or tingling. The shoulder pain continued to increase throughout the neuro exam until the diver "was distracted and unwilling to answer questions." The exam was interrupted to begin recompression. At this time the diver also developed left flank, stomach, and bilateral calf pains (note: the attending DMO ruled the calf pains to be exercise-related as they increased with muscle movement).

Treatment began at 1152 hr. Diver reported partial relief of symptoms at 40 fsw, and complete relief of the bilateral shoulder, flank and stomach pains upon reaching the treatment depth of 60 fsw. A neurological exam was completed by the attending DMT at depth and no neurological deficits were noted (note: the DMO reported pan-hyperreflexia, graded 3+ throughout, which he attributed to shivering). A USN TT6 was completed with no extension. On 19 Sep 97 the subject was reexamined and found asymptomatic without interval recurrence of symptoms, or sequelae.

Case: o
Subject #59
Dive Date: 02 Oct 95
Dive Profile: FD01
Reached Surface: 1007
Treatment Date: 02 Oct 95
**NMRI DMO Diagnosis: Acute, neurological and limb pain decompression illness
(DCS Type II)**

Diver surfaced asymptomatic, but within 5 minutes he noticed a poorly localized left elbow pain, rapidly increasing to 4/10 intensity, non-radiating, unrelieved by movement or posture. A rapid neurological screen was normal. He was recompressed to 60 fsw on oxygen (1022) and had immediate resolution of his elbow pain during compression. As the pain was subsiding he noticed a "feeling of puffiness" in the 4th and 5th digit and ulnar margin of the left hand. The fingertips felt "numb". Within 2 minutes of reaching 60 fsw these sensory abnormalities completely resolved. He was treated on USN TT6, no extensions. During the end of treatment he reported retrosternal discomfort that was relieved by humidifying the oxygen. Other than the retrosternal discomfort he surfaced from treatment asymptomatic. A full neurological exam after treatment was normal. At the 24-hour check he was asymptomatic, with no recurrence of arm symptoms; mild symptoms of oxygen toxicity were resolving.

Case: p
Subject #6
Dive Date: 03 Oct 95
Dive Profile: FD02
Reached Surface: 0939
Treatment Date: 03 Oct 95
NMRI DMO Diagnosis: DCS Type I

Diver became symptomatic while exiting the water reporting a low grade (1/10) right shoulder pain aggravated by movement. At the 10 minute examination it was evident that this pain was centered in the right bicipital groove and continued to be aggravated by compression and movement. The neurological exam was normal. He was observed until 2 hours after surfacing at which time his symptoms had not changed. After another hour of observation he reported an increase in the intensity of the right shoulder pain to mild. He was recompressed (1252) and reported slight relief upon reaching 60 fsw, with complete relief after 3 minutes on oxygen at 60 fsw. He continued to have slight pain with deep palpation throughout treatment, although it was markedly decreased. USN TT5 was completed and post-treatment neurological exams were normal. Diver remained asymptomatic through the 24 hour post-treatment exam.

Case: q
Subject #18
Dive Date: 17 Oct 95
Dive Profile: GD01
Reached Surface: 1239
Treatment Date: 18, 20, 21 Oct 95
NMRI DMO Diagnosis: DCS Type II

Diver surfaced asymptomatic but complained of inguinal pruritis at the 10-minute check which waned, but he then developed lightheadedness, shortness of breath and abdominal pain. He also developed chest pain, worse with deep inspiration and which was accompanied by a cough. On exam he was found to be in mild distress but otherwise without significant findings. At approximately 1252 the diver was recompressed on 100% oxygen to 60 fsw. His abdominal pain improved, but he developed a low-grade left back/flank pain. His skin also developed a mild cyanosis across the abdomen, which transformed to a lightly erythematous rash with pressure. A full neurological exam was unremarkable. By 1339 the various symptoms began to fade with complete resolution of all pain symptoms at 1439. A TT6 (2 extensions @ 60 fsw) was completed on 17 Oct 95 and the diver surfaced asymptomatic except for mild abdominal muscle soreness. Two-hour post-treatment check was unchanged. A post-dive CXR was completed and found normal. The following day, approximately 18 hours post-treatment the diver awoke with a headache, increased abdominal pain and new onset of left shoulder soreness. He was recompressed and re-treated on TT6 (2 extensions at 30 fsw) on 18 Oct @ 0813 and reported improvement in shoulder pain from 3/10 to 2/10 in intensity. During the second treatment he developed left hand paresthesia which did not improve significantly despite oxygen period extensions. He had mild subjective improvement at 2-hour and 6-hour post-treatment checks, with residual left shoulder and left thigh and inguinal pain.

Case: q (continued)

On the following morning, 19 Oct 95, the diver reported marked improvement in his symptoms. He exhibited signs of both Draeger's ear and pulmonary oxygen toxicity so was not treated with hyperbaric oxygen. On 20 Oct 95 the diver reported further subjective improvement of his symptoms, but with new aching in his right groin, and fleeting headache, occasional muscle twitches and mild pain in dorsum or right wrist. He was recompressed and a TT5 was completed on 20 Oct @ 0838. He surfaced with resolution of his groin pain, but residual abdominal and thigh pain. 10-minute and 2-hour checks were unchanged. On the next day, 21 Oct @ 0610, the diver was treated for a fourth and final time using a modified Kindwall (90 min oxygen @ 45 fsw). No residual symptoms.

Summary of Treatments:

17 Oct	Dive & Treatment #1	TT6 with 2 extensions @ 60 fsw
18 Oct	Treatment #2	TT6 with 2 extensions @ 30 fsw
19 Oct	No Treatment	Symptoms of pulmonary O ₂ toxicity
20 Oct	Treatment #3	TT5
21 Oct	Treatment #4	Modified Kindwall, 45 min @ 90 fsw

Case: r

Subject #58

Dive Date: 17 Oct 95

Dive Profile: GD01

Reached Surface: 1239

Treatment Date: 17 Oct 95

NMRI DMO Diagnosis: DCS Type I

Diver surfaced asymptomatic but noticed persistent right elbow pain (2/10) approximately 5 minutes after surfacing. At the 10-minute check the pain was dull, non-radiating and not affected by palpation or movement. A neurological exam of the right upper extremity was normal. The remainder of his neurological exam was remarkable only for errors in recalled objects (1 of 3 at 5 minutes), serial seven, and money calculations. The diver did not complain of nor exhibit any mental status changes. He was recompressed to 60 fsw on 100% oxygen at 1249, with improvement in pain from 3/10 to 1/10. Complete relief of all symptoms after 3 minutes of first oxygen period. The neurological exam remained unchanged. A USN TT6 was started at 1259 and completed with one extension. 2-hour and 18-hour post-treatment checks were unremarkable.

[note: the attending DMO attributed the diver's early errors in mental status exam to the frenzied distractions of treating another seriously injured diver while the mental status tests were being administered].

Case: s
Subject #6
Dive Date: 19 Oct 95
Dive Profile: HB02
Reached Surface: 1456
Treatment Date: 19 Oct 95
NMRI DMO Diagnosis: DCS Type I

Diver reported 1/10 pain in left elbow at the 10 minute post-dive check; pain was intermittent, lasting several seconds, with 10-15 seconds relief between episodes. At 42 min post dive the pain began to spread up the arm from the elbow, still intermittent, but clearly worsening. The diver stated that he thought he was bent based on a Type I bend he was diagnosed with 16 days earlier (profile: 230'/:25). A full neurological exam was within normal limits. Subject diagnosed with Type I (pain only) DCS, but DMO recommended treatment with a USN TT6 (no extensions) because of subject's plans to fly 36 hours post-dive. Treatment began at 1537 and diver reported partial symptom relief at 23 fsw with full relief at 37 fsw. Normal neuro exam and mild respiratory discomfort upon treatment completion. The subject remained asymptomatic 12 hours later, with only slight ear discomfort.

Case: t
Subject #53
Dive Date: 07 Feb 96
Dive Profile: HD04
Reached Surface: n/a
Treatment Date: 07, 08 Feb 96
NMRI DMO Diagnosis: DCS Type II (Pain under pressure)
Acute progressive limb and peripheral nerve DCS

Diver developed pain in his left forearm 10 minutes into a 20 fsw in-water decompression stop at 1245. The pain progressed to 10/10 and he developed left hand tingling sensation and difficulty with hand flexion and extension. Diver was removed from water and recompressed in chamber on 100% O₂ to 30 fsw (1257). He noted partial relief at 30 fsw, then improvement at 60 fsw with residual fingertip tingling. By 1335 all pain and tingling resolved with some residual left forearm soreness. A TT6 was extended for one period at 60 fsw. Midway through the 2nd O₂ period at 30 fsw he reported left arm swelling with a feeling of "tightness". He was extended an additional O₂ period, given Ibuprofen 800 mg PO and reported some relief of tightness. TT6 (with 2 extensions) was completed with residual soreness and swelling, without erythema or tenderness; remainder of post-treatment neurological exam was unremarkable.

Approximately 6 hours after treatment he awoke with recurrence of left forearm pain (1/10), associated with tingling in his fingertips. He self-medicated with Ibuprofen 800 mg with symptomatic improvement. Two hours later he again awoke with left forearm pain, fingertip tingling and left palmer numbness. He was recompressed to 60 fsw (~0425). A TT6 was completed (0955) without relief of symptoms. The diver was referred to NNMC Neurology for nerve conduction studies and MRI with return to pre-dive baseline in two weeks.

Case: u
Subject #18
Dive Date: 06 Mar 96
Dive Profile: IB03
Reached Surface: 1227
Treatment Date: 06 Mar 96
NMRI DMO Diagnosis: DCI Type II

Diver remained asymptomatic until approx. 3.5 hours after surfacing at which time he developed soreness in left forearm that progressed to frank joint pain and left hand weakness over the next 45 minutes. The diver was at home when this occurred and during the hour and 15 minutes it took for him to reach the chamber the pain continued to increase to 9/10, radiated into his shoulder and hand, and his left hand weakness became more pronounced. A brief neurological exam prior to treatment confirmed the weakness in his left hand grip strength, but normal sensation to fine touch in the arms and hands. He was recompressed (1809) to 60 fsw on oxygen and reported improvement in the pain to 7/10. Pain continued to improve during the first oxygen period at 60 fsw to 5/10 and localized to the elbow. A complete neurological exam during treatment revealed clumsiness with rapid alternating movements of the left hand, weakness of the left biceps, wrist flexors and extensors, and intrinsic muscles of the left hand, and absent upper extremity reflexes. He reported complete relief of all symptoms halfway through the second oxygen period at 60 fsw. At 30 fsw he complained of irritation while breathing and a feeling of mild fullness in his chest; he was given a 5 minute air break which relieved these symptoms. USN TT6 with one extension at 60 fsw was completed without recurrence of symptoms.

He remained asymptomatic after treatment and a complete neurological exam was normal. Physical exam was normal except for mild chest fullness and cough on inspiration. 8 hours after treatment he remained free of any DCS symptoms, but had a residual feeling of chest fullness, mild muscle aches and upper respiratory congestion, although he not longer coughed with deep inspiration. Left elbow was free of pain and left hand functioned normally. No residual symptoms.

Case: v
Subject #74
Dive Date: 07 Mar 96
Dive Profile: IB04
Reached Surface: 1235
Treatment Date: 07 Mar 96
NMRI DMO Diagnosis: DCS Type II

Diver surfaced with complaint of cold but was otherwise asymptomatic through the 10-minute check. At 1350 he presented with a complaint of unclear, fuzzy vision "as if looking at an object through/under the water" in his left peripheral field. He was otherwise asymptomatic. A neurological exam revealed a left eye monocular temporal crescent-shaped defect, mostly categorized by the diver as blurring of vision, and not total. The DMO assessed the defect as involving the most peripheral portion of the left temporal field, without right eye involvement. Visual acuity and all other clinical ophthalmologic and neurological checks were normal. The diver was recompressed to 60 fsw on 100% oxygen at 1403. At the end of one oxygen period extension he reported no improvement in visual symptoms and was further compressed to

Case v (continued)

100 fsw on air @ 1544; improvement was noted at 1549. The diver was placed in 59% oxygen @ 1607, and reported complete resolution of his visual field defect at 1624. A COMEX treatment table 30 (CX30) was conducted. During treatment he developed a mild (1/10) bifrontal non-throbbing headache, treated with 650 mg Aspirin, and increased fluid intake. He also developed mild burning chest pain, was diagnosed with pulmonary oxygen toxicity and shifted to 52% oxygen, and decreased oxygen period while at 60 fsw. A CX30 was completed without extensions. A post-treatment neurological exam was normal without symptoms of pulmonary toxicity. The diver was referred to NNMC Neurology and Ophthalmology for evaluation. No recurrence of symptoms or sequelae.

Case: w

Subject #32

Dive Date: 07 Mar 96

Dive Profile: IB04

Reached Surface: 1235

Treatment Date: 08 Mar 96

NMRI DMO Diagnosis: DCS Type I (slowly progressive musculoskeletal)

Diver was asymptomatic upon surfacing and through the 10-minute check, but reported "tightness" around his right elbow approximately 15 minutes after surfacing. He denied joint pain, and attributed the tightness to wetsuit squeeze and coldness of the dive. A neurological exam was normal with no focal sensory or motor findings in his right upper extremity. The diver was completely asymptomatic at 1305 and cleared by DMO. Upon waking the next day (08 Mar 96 @ 0600) he noted left knee pain with exercise, increasing to 7/10 in severity with deep knee bends. A neurological exam was unremarkable except for his subjective report of knee pain and he was recompressed to 60 fsw on 100% oxygen (0907). During the treatment his pain decreased to 4/10 at 0918 and 2/10 at 0946, with complete resolution of symptoms at 1022. A USN TT6 (with one extension) was completed. His neurological exam upon surfacing and 1-hour post-treatment was unremarkable; no pain sequelae.

Case: x

Subject #33

Dive Date: 12 Apr 96

Dive Profile: IE08

Reached Surface: 1214

Treatment Date: 12 Apr 96

NMRI DMO Diagnosis: DCS Type I

Diver surfaced and remained asymptomatic through the 10-minute post-dive check, but complained of "some niggles" about his left elbow at the 2-hour post-dive check. He noted fleeting pains once or twice during the previous 2 hours, and felt it was related to trauma the day before. A neurological exam was completely normal. En route home at 1530 the diver noted left shoulder pain which increased in severity, and progressed to bilateral shoulder pain, with decreased left arm strength. He returned to NMRI and at 1736 he was recompressed on 100% oxygen. A neurological exam at depth revealed 8-9/10 deep left shoulder joint pain with radiation to left biceps, and marked weakness of all muscle groups in left upper

Case x (continued)

extremity. Remainder of neurological exam was normal. The diver was unable to find a comfortable position for his left shoulder. By 1751 he reported complete relief of right shoulder pain, and improved strength in his left upper extremity. Complete relief of all symptoms at 1906. A TT6 (with 2 extensions at 60 fsw) was completed. Neurological exam on surfacing was normal. All subsequent exams were unremarkable, with no sequelae.

Case: y***Subject # 42****Dive Date: 14 Jun 95****Dive Profile: DD02****Reached Surface: 0927****Treatment Date: no treatment****NMRI DMO Diagnosis: DCS Type I**

Diver was asymptomatic at the 10 minute check except for left ear "cracking" but denied ear pain. At the 2 hour check the diver was completely without symptoms. When he reported to medical for the 24 hr check at 0700 the following day he complained of a dull (2-3/10) ache in his right hip which had occurred at some unspecified time before the 24 hour check. The pain spontaneously resolved after about 130 minutes, and was not present at the 24 hour check. No treatment was judged necessary and there was no recurrence of the hip pain.

Case: z***Subject #16****Dive Date: 12 Sep 95****Dive Profile: ED04****Reached Surface: 1141****Treatment Date: no treatment****NMRI DMO Diagnosis: DCS Type I**

Diver was asymptomatic upon surfacing, at the 10-minute check and at the 2-hour check. At the 24-hour check he reported that approximately 7.5 hours after surfacing he experienced right knee pain. At its worst, the pain was 7/10 in severity and increased with movement. The duration of the most intense pain was about 20 minutes then decreased to a low grade pain and lasted approximately 2 hours. The knee pain had fully resolved and there were no other symptoms at the 24-hour check.

*diagnosed retrospectively by DMO panel (see page 11 of text)

Appendix 5: Marginal Case Descriptions

Case: aa

Subject #53

Dive Date: 27 Feb 95

Dive Profile: AA07

Reached Surface: 1019

After showering, approximately 10 minutes post dive, the diver had a sudden onset of an ache in the left shoulder, "like he'd been punched". Pain was constant, not throbbing; duration about 10 minutes, then suddenly resolved. No fatigue, no numbness, felt fine after pain resolution. Assessed by DMO as a niggle; no need for treatment.

Case: ab

Subject #43

Dive Date: 28 Feb 95

Dive Profile: AB01

Reached Surface: 1017

No complaints post-dive, 10 mins or 2 hr checks. At the 24-hour check diver reported that shortly after surfacing he noted a mild abdominal discomfort that resolved within 15 minutes and a dull ache in his right hip the day before; hip pain began approx. 8 hours post-dive and gradually improved during the next 4 hours when it was fully resolved. No residual pain at the 24 hour check.

Case: ac

Subject #35

Dive Date: 20 Mar 95

Dive Profile: BA01

Reached Surface: 1045

No symptoms at the 10 min or 2 hour checks. At the 24 hour check the diver reported that while driving home from work (approx. 6 hrs post dive) with his left arm propped up on the car window he noted a "niggle". He described it as a tingling sensation from the left elbow to his fingertips that lasted < 1 minute. He reported that there was no pain or skin changes. Completely resolved and asymptomatic at the 24 hour check.

Case: ad
Subject #51
Dive Date: 09 May 95
Dive Profile: CE01
Reached Surface: 0954

Less than 2 mins after surfacing the diver reported a shooting, "stabbing" pain in his right shoulder. Rated as 3/10 in severity at its worst point, it completely resolved by 12 minutes post dive. No further symptoms.

Case: ae
Subject #4
Dive Date: 05 Sep 95
Dive Profile: EB03
Reached Surface: 1121

45 minutes after surfacing the diver experienced 10 minutes of blurred vision (no double vision) and difficulty focusing. He reported intermittent pain in his right thumb 1 hr 15 min post dive. At 1 hr 30 min he complained of itching that decreased after 30 minutes. The diver reported some fatigue; at 3 hours post-dive all symptoms had resolved completely.

Case: af
Subject #74
Dive Date: 11 Sep 95
Dive Profile: ED02
Reached Surface: 1059

Within 2 mins of surfacing diver report itching on his back. At 30 mins post-dive he complained of an unspecified joint erythema and a (1/10) discomfort in the mid-ulnar aspect of right forearm that was relieved/aggravated by massage. Neurological exam was normal. Approx. 8 hrs post-dive the subject experienced niggles (1/10) in his right knee that increased with activity; duration of niggles about 15 minutes. All symptoms had fully resolved by the 24 hour check, but the diver did report being "a little tired" at that time.

Case: ag*
Subject #13
Dive Date: 01 Apr 96
Dive Profile: IE04
Reached Surface: 1231

Reported that his knees hurt on the bottom during the bike ride, but had fully resolved before reaching surface (DMO notes: consistent with compression arthralgia). At the 24-hour check he reported that he had a left hip pain from 1700-2100 the evening after the dive. The attending DMO noted that this was possibly niggles.

Case: ah*
Subject #21
Dive Date: 27 Feb 96
Dive Profile: IA01
Reached Surface: 1313

No symptoms through the 2-hour check. At the 24-hour check he reported having a niggle in his right anterior ankle at 2000-2200 the night before. He was asymptomatic at the 24-hour check.

Case: ai
Subject #21
Dive Date: 16 Oct 95
Dive Profile: GB02
Reached Surface: 1042

Some time between 40 minutes post-dive and the 2 hour check, the diver experienced a niggle in right elbow that completely resolved with no recurrence. No complaints at the 2 hour check.

Case: aj
Subject #75
Dive Date: 17 Oct 95
Dive Profile: GD01
Reached Surface: 1239

No symptoms upon surfacing, at 10 min or 2 hr checks. At 24 hr diver reported "left shoulder left wrist right pointer and index pain" that "lasted 2-3 minutes". (Records do not provide any indication as to time of onset). Diver also reported increased fatigue at the 24 hr check, but "not excessive".

Case: ak
Subject #4
Dive Date: 20 Oct 95
Dive Profile: HB03
Reached Surface: 1050

Reported itching of left elbow and left upper pectoral region at 10 minute check; no rash and the itching resolved. Between the 10 minute and 2 hour checks a fleeting itch developed in the right wrist, then on the central abdomen. Diver reported scratching his abdomen approx. 15 min before the 2 hr check and he noticed a mild superficial erythematous rash on the abdomen that blanched with digital pressure. At 2 hr 20 min post dive, all itching was fully resolved and the rash barely detectable.

Case: al*
Subject #22
Dive Date: 10 May 95
Dive Profile: CE02
Reached Surface: 1014

At the 10-minute check the diver complained of right sternoclavicular joint pain that began about 8 minutes after surfacing. He reported that it was markedly resolved by the 10-minutes check, but still somewhat sore. At the 2-hour check the pain had fully resolved. No symptoms at 24-hour check.

Case: am
Subject #52
Dive Date: 29 Feb 96
Dive Profile: IA03
Reached Surface: 1317

Approx. 9 hours after surfacing diver noticed a low grade steady pain in his left hip. He also complained of a sore throat and felt chilled; took a Tylenol and went to sleep. He awoke 2 hrs later feeling "hot", but the hip pain and sore throat had resolved. Pre-dive notes indicate that he was recovering from a cold at the time of the dive. At the 24 hour check he was free of symptoms.

Case: an
Subject #18
Dive Date: 01 Mar 96
Dive Profile: IA04
Reached Surface: 1230

Diver had no complaints at the 10 min check, but felt tired at the 2 hr check. At the 24 hour check he reported that approx. 6.5 hrs post dive he had a mild pain in the right knee that lasted about 20 mins; pain was non-radiating and resolved spontaneously (DMO's impression - "niggle"). Diver had no symptoms at the 24 hr check.

Case: ao
Subject #54
Dive Date: 05 Mar 96
Dive Profile: IB02
Reached Surface: 1205

No symptoms at 10 min check but sometime after the diver noticed a left knee pain that lasted until shortly before the 2 hour check. No symptoms at the 2-hour check. At 24 hrs diver reported feeling more tired than after most other dives, but not excessive.

Case: ap
Subject #57
Dive Date: 10 Apr 96
Dive Profile: IE07
Reached Surface: 1233

At 10 min check diver reported right knee pain (1/10) that began just after clean time; lasted about 20 mins and resolved completely after he removed his wet suit. No symptoms at 2 hr or 24 hr checks. DMO noted that this was "probably a niggles".

Case: aq*
Subject #22
Dive Date: 14 Feb 95
Dive Profile: AA02
Reached Surface: 1114

No symptoms through the 2-hour check. At the 24-hour check he reported that shoulder niggles had occurred yesterday afternoon (the day of the dive) and lasted for approximately 5 minutes. No other complaints and he remained asymptomatic at the 24-hour check.

Case: ar*
Subject #42
Dive Date: 15 May 95
Dive Profile: CE04
Reached Surface: 1135

About 12-15 minutes after surfacing diver had a dull ache pain in his right leg above the knee. He reported that it came on quickly and lasted about 2 minutes before resolving completely. Was asymptomatic at the 2-hour check.

Case: as*
Subject #49
Dive Date: 20 Mar 95
Dive Profile: BA01
Reached Surface: 1045

At 2-3 minutes after surfacing he noted a dull, aching pain in his right posterior buttock; 3-5/10 in severity and it persisted 4-5 minutes. This pain was then followed by approximately 5 minutes of "spasm-like" cramping pain in the right inguinal region. All symptoms completely resolved without recurrence or sequelae by 15 min post-dive. DMO noted that these were niggles. The diver remained asymptomatic at the 2-hour and 24-hour checks.

Case: at*
Subject #58
Dive Date: 10 Apr 96
Dive Profile: IE07
Reached Surface: 1233

Ten minutes after surfacing diver developed a purple rash on back and shoulders that blanched on touch. There was no itching or other symptoms. At the 2-hour check a mild red rash was diffuse on the back and neck, but was resolving; also reported mild fatigue at the 2-hour check. All symptoms fully resolved by the 24-hour check.

Case: au*
Subject #61
Dive Date: 02 Apr 96
Dive Profile: IE05 Reached Surface: 1239

At the 10-minute check the diver reported having had minor niggles in his left elbow and left wrist on arrival at the 30' stop. The discomfort dissipated during the 30' stop without recurrence. He remained asymptomatic at the 2-hour and 24-hour checks.

Case: av*
Subject #69
Dive Date: 01 Mar 95
Dive Profile: AB02
Reached Surface: 1015

No symptoms at 10-minute or 2-hour checks. At the 24-hour check he reported a "washed out feeling" yesterday afternoon (day of the dive) and that he slept for 12 hours.

*diagnosed retrospectively by DMO panel (see page 11 of text)

Appendix 6: Data Set NMR9404 Summary

Dive Name	Profile #	Outcome D=DCS M=Marginal (case)	# Divers	Depth (fsw)	Bottom Time (min)	Ascent Time (min)	T ₁ after surfacing (min)	T ₂
AA01	1		4	120.0	27.0	5.5		
AA02	2		3	119.0	27.1	5.0		
AA02	3	M(aq)	1	119.0	27.1	5.0	119.7	299.7
AA03	4		4	119.0	27.0	5.3		
AA04	5		3	119.0	27.2	4.9		
AA04	6	D(a)	1	119.0	27.2	4.9	120.0	1080.0
AA06	7		4	119.0	27.0	5.4		
AA07	8		3	119.0	27.0	5.7		
AA07	9	M(aa)	1	119.0	27.0	5.7	-6.7	20.0
AB01	10		3	119.0	32.0	6.1		
AB01	11	M(ab)	1	119.0	32.0	6.1	120.0	480.0
AB02	12		3	119.0	32.1	5.3		
AB02	13	M(av)	1	119.0	32.1	5.3	120.0	300.0
AB03	14		4	119.0	32.1	5.6		
AB04	15		3	119.0	32.0	5.7		
AB04	16	D(b)	1	119.0	32.0	5.7	10.0	17.5
AB05	17		3	119.0	32.0	5.2		
AB05	18	D(c)	1	119.0	32.0	5.2	-6.0	5.0
AE01	19		3	119.0	30.1	5.2		
AE02	20		4	118.8	30.0	5.6		
AE03	21		4	119.0	30.0	5.4		
AE04	22		3	119.0	30.0	5.2		
AE05	23		2	119.0	30.0	5.1		
BA01	24		2	160.0	13.0	6.6		
BA01	25	M(as)	1	160.0	13.0	6.6	-7.2	15.0
BA01	26	M(ac)	1	160.0	13.0	6.6	120.0	360.0
BA02	27		4	160.0	13.0	7.0		
BA03	28		4	160.0	13.0	6.8		
BA04	29		3	160.0	13.1	6.7		
BA04	30	D(d)	1	160.0	13.1	6.7	-7.0	25.0
BA05	31		4	160.0	13.1	7.3		
BA06	32		4	160.0	13.1	6.5		
BB01	33		4	160.0	16.1	7.3		
BB02	34		4	160.0	16.0	6.0		
BB03	35		4	160.0	16.1	6.2		
BB04	36		4	160.0	16.0	6.6		
BD01	37		3	160.0	18.1	6.6		
BD01	38	D(e)	1	160.0	18.1	6.6	10.0	25.0
CA02	39		4	200.0	9.0	7.8		
CA04	40		4	200.0	9.0	8.3		
CA05	41		4	200.0	9.1	8.2		
CA06	42		4	200.0	9.0	7.6		
CB01	43		4	200.0	11.0	7.8		
CB02	44		3	200.0	11.1	8.6		
CB02	45	D(f)	1	200.0	11.1	8.6	-9.2	12.0
CB03	46		4	200.0	11.0	8.3		
CB04	47		4	200.0	11.0	8.7		
CB05	48		4	200.0	11.0	8.1		
CB06	49		3	200.0	11.0	8.8		
CB06	50	D(g)	1	200.0	11.0	8.8	-9.3	15.0
CE01	51		3	200.0	10.0	8.1		
CE01	52	M(ad)	1	200.0	10.0	8.1	-8.9	12.0
CE02	53		3	200.0	10.0	8.3		

CE02	54	M(al)	1	200.0	10.0	8.3	-8.6	7.9
CE03	55		4	200.0	10.0	7.9		
CE04	56		2	200.0	10.0	7.7		
CE04	57	M(ar)	1	200.0	10.0	7.7	-8.3	11.9
CE04	58	D(h)	1	200.0	10.0	7.7	0	20.0
DA01	59		4	160.0	25.0	37.6		
DA02	60		4	160.0	25.0	37.7		
DA03	61		4	160.0	25.0	37.7		
DA04	62		4	160.0	25.0	37.3		
DB01	63		4	160.0	25.0	27.8		
DB03	64		4	160.0	25.1	27.0		
DB04	65		4	160.0	25.1	27.8		
DB05	66		4	160.0	25.1	26.8		
DD01	67		4	160.0	25.2	16.8		
DD02	68		2	160.0	25.1	16.8		
DD02	69	D(y)	1	160.0	25.1	16.8	120.0	1300.0
DD02	70	D(i)	1	160.0	25.1	16.8	0	120.0
DD04	71		3	160.0	24.9	17.2		
DD04	72	D(j)	1	160.0	24.9	17.2	120.0	420.0
DD05	73		4	160.0	24.1	16.8		
DD06	74		4	160.0	25.0	16.6		
DD07	75		3	160.0	25.0	17.1		
DD07	76	D(k)	1	160.0	25.0	17.1	17.9	1400.0
DD08	77		4	160.0	25.0	16.8		
EA02	78		3	200.0	25.0	64.1		
EA02b=blu divr	79		1	200.0	25.0	64.1		
EA03	80		4	200.0	25.1	64.4		
EA04	81		4	200.0	23.9	64.6		
EA05	82		4	200.0	25.0	63.7		
EB01	83		4	200.0	25.0	49.8		
EB02	84		4	200.0	25.1	50.4		
EB03	85		3	200.0	25.1	48.6		
EB03	86	M(ae)	1	200.0	25.1	48.6	0	75.0
EB04	87		3	200.0	24.9	48.9		
EB04	88	D(l)	1	200.0	24.9	48.9	120.0	600.0
EB05	89		4	200.0	25.0	48.5		
ED01	90		4	200.0	25.0	28.5		
ED02	91		2	200.0	25.0	28.7		
ED02	92	M(af)	1	200.0	25.0	28.7	0	480.0
ED02	93	D(m)	1	200.0	25.0	28.7	-8.0	2.0
ED03	94		4	200.0	25.0	28.6		
ED04	95		2	200.0	25.0	28.9		
ED04	96	D(z)	1	200.0	25.0	28.9	120.0	450.0
ED04	97	D(n)	1	200.0	25.0	28.9	-8.1	10.0
FA01	98		4	230.0	25.1	10.0		
FA02	99		4	230.0	25.0	109.7		
FA03	100		4	230.0	25.1	111.0		
FA04	101		3	230.0	25.4	110.2		
FA04b=blu divr	102		1	230.0	25.4	110.2		
FA05	103		3	230.0	25.1	111.7		
FB01	104		4	230.0	25.1	76.2		
FB02	105		4	230.0	25.0	78.5		
FB03	106		3	230.0	25.0	75.3		
FB04	107		4	230.0	25.0	75.4		
FB05	108		3	230.0	25.0	75.3		
FD01	109		3	230.0	25.0	40.3		
FD01	110	D(o)	1	230.0	25.0	40.3	-8.2	5.0
FD02	111		3	230.0	25.0	40.1		
FD02	112	D(p)	1	230.0	25.0	40.1	-2.6	180.0
FD03	113		4	230.0	24.9	39.3		

GA01	114		4	260.0	20.0	111.0		
GA03	115		4	260.0	19.9	112.1		
GA04	116		4	260.0	20.0	110.4		
GA05	117		4	260.0	20.1	111.0		
GB01	118		4	260.0	20.0	75.4		
GB02	119		3	260.0	20.1	77.0		
GB02	120	M(ai)	1	260.0	20.1	77.0	10.0	40.0
GB03	121		4	260.0	20.0	76.1		
GB04	122		4	260.0	19.9	75.5		
GD01	123		1	260.0	19.8	41.0		
GD01	124	M(aj)	1	260.0	19.8	41.0	120.0	1440.0
GD01	125	D(q)	1	260.0	19.8	41.0	-8.4	10.0
GD01	126	D(r)	1	260.0	19.8	41.0	-8.4	10.0
HB01	127		4	260.0	25.0	130.9		
HB02	128		3	260.0	24.8	130.8		
HB02	129	D(s)	1	260.0	24.8	130.8	-2.3	41.0
HB03	130		3	260.0	24.9	130.3		
HB03	131	M(ak)	1	260.0	24.9	130.3	0	140.0
HB04	132		4	260.0	25.0	130.3		
HB05	133		4	260.0	25.3	130.0		
HB07	134		4	260.0	25.1	131.5		
HD01	135		4	260.0	25.0	106.8		
HD03	136		4	260.0	25.0	106.5		
HD04	137		3	260.0	25.1	66.3		
HD04	138	D(t)	1	260.0	25.1	66.3	-5.8	10.4
HD06	139		3	260.0	24.6	107.0		
HD07	140		4	260.0	25.4	105.9		
HD08	141		4	260.0	25.0	105.2		
HD09	142		3	260.0	25.0	105.6		
HD09g=grn divr	143		1	260.0	25.0	105.6		
IA01	144		3	300.0	25.4	202.2		
IA01	145	M(ah)	1	300.0	25.4	202.2	119.9	526.9
IA02	146		4	300.0	25.0	203.0		
IA03	147		3	300.0	25.1	203.4		
IA03	148	M(am)	1	300.0	25.1	203.4	120.0	550.0
IA04	149		3	300.0	25.1	204.8		
IA04	150	M(an)	1	300.0	25.1	204.8	120.0	390.0
IB01	151		4	300.0	25.0	177.1		
IB02	152		3	300.0	25.1	177.2		
IB02	153	M(ao)	1	300.0	25.1	177.2	10.0	120.0
IB03	154		3	300.0	25.0	177.1		
IB03	155	D(u)	1	300.0	25.0	177.1	120.0	210.0
IB04	156		2	300.0	25.0	178.6		
IB04	157	D(v)	1	300.0	25.0	178.6	10.0	73.0
IB04	158	D(w)	1	300.0	25.0	178.6	120.0	1047.0
IE01	159		4	300.0	25.1	193.8		
IE02	160		4	300.0	25.0	192.0		
IE03	161		4	300.0	25.1	193.5		
IE04	162		3	300.0	25.0	191.8		
IE04	163	M(ag)	1	300.0	25.0	191.8	120.0	270.0
IE05	164		3	300.0	24.9	192.3		
IE05	165	M(au)	1	300.0	24.9	192.3	-143.8	-108.4
IE07	166		2	300.0	24.9	192.0		
IE07	167	M(ap)	1	300.0	24.9	192.0	-107.9	30.0
IE07	168	M(at)	1	300.0	24.9	192.0	0	120.0
IE08	169		3	300.0	25.0	192.4		
IE08	170	D(x)	1	300.0	25.0	192.4	10.0	196.0
IE09	171		4	300.0	24.9	193.8		

Appendix 7: Diagnostic criteria for DCS events

Diagnosis Criteria: from REVISION 22 NOV 1988, Weathersby, et al.

First step: Separate outcome into 3 categories:

Cat A. Definite DCS (Symptom within 24 hour unless Sat dive)

Cat B. Unknown Outcome

Cat C. Not DCS

Second Step: Separate Cat A further:

Cat A-1 Definite DCS. Requiring recompression therapy by 1988 standards

Cat A-2 Definite DCS. NOT requiring recompression by 1988 standards. Difference between A-1 and A-2 is 1988 perception of whether lack of treatment will lead to morbidity in the diver.

Specific Description:

Cat A-1. Definite DCS requiring recompression.

- Any suspicious symptoms leading to and relieved by recompression
- Joint pain persisting as tabulated below whether recompressed or not:

		One Joint	Multiple Joints
Pain	Mild	60 min +	30 min +
	Moderate	30 min +	15 min +
	Severe	15 min +	8 min +

- Dyspnea, unless clearly from barotrauma or anxiety hyperventilation syndrome
- Any spinal neurologic symptoms, supported by signs, regardless of duration
- Any brain symptoms, such as visual blurring, "mental sluggishness", regardless of duration
- Any inner ear symptom, such as unsteadiness, vertigo, hearing loss, unless clearly from barotrauma

Cat A-2. Definite DCS not requiring recompression.

- Joint pain not persisting as long as tabulated under A-1
- Fatigue, moderate or severe
- Skin itch in immersed air or N₂-O₂ dives (Itch in dry chamber dives and HeO₂ dives is probably due to local skin mechanisms that would confuse modeling of primary symptoms)
- Skin rash or mottling, if only symptoms (When combined with non-persistent (A-2) joint pain becomes A-1).
- (Default diagnosis) Symptoms reported as "Mild bends, not requiring recompression" which do not fit other categorization criteria

Cat B. Unknown outcome; data insufficient for 1988 diagnosis

- Headache, typical and common for this diver
- Vague abdominal pain, not related to trauma or barotrauma
- Vague chest pain, not related to trauma or barotrauma
- Vague symptoms of any kind NOT responding to recompression or oxygen therapy attempted soon after dive (say 18 hours for non-sat dive).

Cat C. Not DCS

- No post-dive symptoms reported
- Joint pain or fatigue, mild and consistent with recent exercise
- Sharp pain, consistent with joint sprain or impact injury
- Vague symptoms similar to Cat A-2 NOT responding to recompression therapy attempted no soon after dive
- Skin itch in dry chamber dives and He-O₂ dives.